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SILVICULTURAL ACTIVITIES AND NON-POINT POLLUTION ABATEMENT: A Cost-Effectiveness Analysis Procedure.

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Silvicultural Activities and Non-Point Pollution Abatement: A Cost-Effectiveness Analysis Procedure.

Authored by a Committee of Scientists of the
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FOREWORD

Environmental protection efforts are increasingly directed towards preventing adverse health and ecological effects associated with secific compounds of natural or human origin. As part of the Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management or engineering tools for assessing and controlling adverse environmental effects of non-irrigated agriculture and of silviculture.

Silvicultural activities that disturb surface soil and cause accelerated rates of erosion are associated with increased sediment loads that adversely affect water quality in a watershed. This report assesses the erosion potential of common silvicultural practices and provides a method to identify costs related to the control of this non-point source of pollution as an aid to forestry managers and water quality planners.

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Director
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Athens, Georgia

PREFACE

The passage of the Water Pollution Control Act Ammendments of 1972 requires that actions be taken to control sources of pollution that affect the nation's waters. One of the areas of concern is the pollution resulting from non-point sources. Non-point source pollution arises from several categories of land use, one of which includes silvicultural activities. Within this category, a major concern is the water quality changes associated with sedimentation that can result when silvicultural activity disturbs the surface soil and causes accelerated rates of soil erosion.

In order to formulate non-point pollution control strategies and plans, it is necessary that the water quality planner be able to recognize the potentials for pollution associated with specific activities. The planner must also be able to identify the costs of controlling the sources of pollution and place these costs in perspective.

This report stems from these two basic requirements:

.A broad level assessment of the erosion potential associated with common silvicultural activities on a nation-wide basis;

.A methodology to identify costs associated with erosion control in order to conduct a cost-effectiveness analysis of erosion control practices.

The assessment of erosion potential is intended to facilitate the identification of potential erosion problems associated with commonly used silvicultural activities. This is presented as a series of regionalized tables. The tables describe the commonly applied silvicultural activities and rank them relative to erosion potential.

The method for cost-effectiveness analysis is presented by discussing the basic concepts of cost-effectiveness analysis and their application to erosion control problems. Examples are provided that illustrate applications of the method.

The non-point pollution phenomenon is extremely complex and to fully describe the relationship between erosion and water quality is beyond the scope of this report. The report is intended to present information that is useful for gaining a perspective on the erosion potential of silvicultural activities and to describe a method that can be used for cost-effectiveness analysis of erosion control practices.

The user of this report must recognize that the erosion potential assessment is not intended to be used as a mandate for change in silvicultural practices or as the specification of site-specific "Best Management Practices." Because of the broad nature of the assessment, much of the site-specific silvicultural information about erosion potential is lost in the aggregation.

The cost-effectiveness methodology relies on input data that are external to this report. The subject data are dependent on highly variable environmental and operational conditions and must be supplied by competent technicians. The method assumes that the precision of the input data is compatible with erosion control goals. It further assumes that the goals are known and that the costs associated with erosion control are at least equal to the benefits.

ABSTRACT

This report focuses upon erosion that contributes to non-point source pollution occurring in forested environments as a result of silvicultural activities. Specifically, the document discusses three topics: (1) silvicultural practices that are currently being applied throughout the United States, with indications of how these practices may affect the rate of erosion, (2) a method for determining the cost-effectiveness of erosion controls that could mitigate or prevent the adverse effects of silvicultural practices, and (3) examples applying the described method for economic analysis using information presented in (1). The information and outlined method are intended for forest managers and water quality planners to enhance analysis and improve decisions concerning the reduction of non-point pollution problems.

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CHAPTER 1

INTRODUCTION

This report is intended to be a tool for both water quality planners and forest land managers who deal with the problem of non-point source pollution, and more specifically, erosion as an indicator of pollution. Clearly, management goals may vary widely among users of this report. Forest managers, for example, have a set of goals that extend beyond the control of non-point water pollution; water quality planners, on the other hand, may be directing their attention solely upon pollution abatement. In either case, this report is intended to serve both classes of users although emphasis is placed on pollution abatement to the diminution of other goals.

Figure 1 shows how the contents of this report interface with overall management strategies. It furnishes information which when integrated with overall objectives in management provides a perspective on the role of erosion control. Once this integration has been achieved, a method for cost-effectiveness analysis is provided as a tool to assist in attaining the objectives.

There are three objectives for this report. This report: (1) broadly summarizes current silvicultural practices in the United States; (2) indicates the erosion potentials associated with these practices; and (3) presents an economic model (cost-effectiveness) for determining the most appropriate controls for reducing erosion.

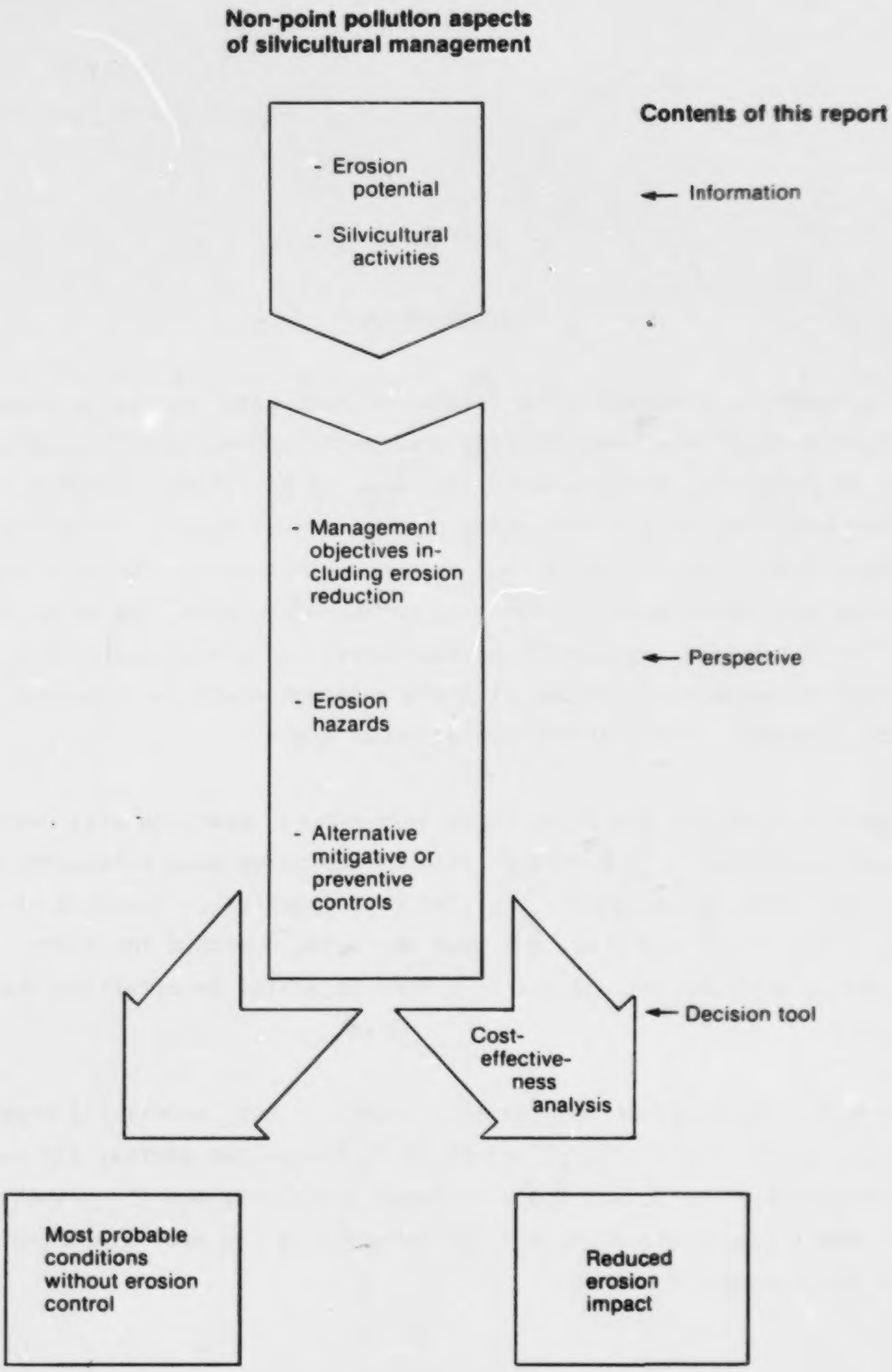
Non-point pollution aspects of silvicultural management
Contents of this report
- Erosion potential
- Silvicultural activities
Information
- Management objectives including erosion reduction
- Erosion hazards
- Alternative mitigative or preventive controls
Perspective
Cost-effectiveness analysis
Decision tool
Most probable conditions without erosion control
Reduced erosion impact

Figure 1. Report contents compared with management objectives.

(1) Silvicultural systems (including access practices) as they are currently applied throughout the United States are summarized (see Tables 2 through 8). This is not a presentation or implication of "best management practices." The purpose is simply to transfer information to the user which will sensitize him to the current operational techniques of silvicultural management. It is broadly based and describes these activities by region while maintaining a national perspective.

(2) Silvicultural activities, including access practices, currently applied are evaluated to assist planners in identifying erosion potentials. The evaluation involves ranking the activities that could contribute to non-point pollution (see Tables 2 through 8). Wide diversity exists in the expertise with which these activities are formulated and carried out as well as the environmental conditions within which forest managers operate. The evaluations reflect these variables.

The report deals with silviculture in its broadest sense: the art and science of cultivating forest crops and the establishment and growth of forests. Activities pertinent to silviculture--harvesting practices, logging systems, slash disposal, intermediate cultural treatments, and the establishment of access--are discussed, as are the major silvicultural systems--clearcut, seed tree, shelterwood and selection. (Refer to the glossary for extended discussions of these important terms.)

Each of the silvicultural systems and the activities related to them interface with the natural environment in ways that could result in non-point pollution from accelerated erosion and mass wasting. Cutting intensities, understory and soil disturbances, and time intervals between activities on a site are major factors influencing the rate of soil loss. However, silvicultural practices can be amended by altering the quantity, nature, or time of the erosion phenomena and thus contribute to non-point pollution reduction.

Controls can be described as "preventive" or "mitigative" according to the mode of application. *Preventive controls* apply to the pre-implementation phase of an operation. These controls involve stopping or changing the activity *before* the soil-disturbing activity has a chance to occur. *Mitigative controls* include vegetative or chemical measures or physical structures which alter the response of the soil disturbing activity *after* it has occurred. Table 1 illustrates some of the major characteristics of the two types of controls and provides some examples.

TABLE 1. CLASSIFICATION OF CONTROL METHODS WITH EXAMPLES

Mitigative	Preventive
A. Surface protection:	A. System design and maintenance
1. Access: Seeding, mulching, riprap, or mat on cut-and-fill slopes	1. Access: Minimize cuts and fills, roadway widths and slopes; control road density
2. Timber harvest: Maintenance of vegetative cover; distribution of slash	2. Timber harvest: Minimize soil compaction from equipment operation; use site-compatible log removal system; control harvested volume within a watershed; limit harvest on unstable slopes
3. Cultural treatments: Seeding; planting; fertilization	3. Cultural treatments: Minimize re-entry disturbances; fire control
B. Flow diversion and energy:	B. Timing:
1. Access: Berms above cut slopes; benches on cut slopes; checkdams in ditches; drop structure at culvert ends; water bars on road surface; flow diversion from potential mass failures or at mid-slope	1. Access: Closure of temporary roads; limited access; closure during adverse conditions
2. Timber harvest: Buffer strips; water bars on skid trails	2. Timber harvest: Limit operation during adverse climatic conditions; site preparations during favorable conditions
3. Cultural practices: Plowing, furrowing, bedding	3. Cultural treatments: Intensive and number of thinnings
C. Access design modification	

(3) A final objective is to present a method for economic evaluation. Several choices may be available for preventing or mitigating erosion. The question then becomes: Which of these is "best"? Cost-effectiveness analysis is provided as one solution to the problem.

....

The following chapters have been developed to meet the three objectives stated above. Chapter 2 contains information describing current silvicultural practices found throughout the country; erosion potentials these activities entail are also described. The chapter is intended primarily as a source of information to planners and managers, both as a description of erosion-related silvicultural activites and as a information reference for persons conducting a cost-effectiveness analysis of erosion controls.

Chapter 3 presents basic concepts underlying cost-effectiveness analysis, with emphasis upon applications of the method to erosion-reduction problems in silviculture. A definition for cost-effectiveness analysis and a comparison with other forms of economic analysis are presented initially. Following this is a step-by-step discussion of the method used to conduct a cost-effectiveness analysis. This chapter should serve both as an introduction to cost-effectiveness analysis for the novice and as a reference to those conducting a current analysis.

The last chapter illustrates procedures for applying cost-effectiveness analysis to erosion problems in silviculture. It begins with a review of the major steps in the method, along with major information requirements and suggested information sources. Following this, examples are presented that illustrate cost-effectiveness analysis in different situations. Reference is made to information presented in Chapter 2.

Finally, glossary and literature cited sections are presented. The glossary contains definition to words and phrases used throughout the text. The literature cited section contains references to the major source documents referred to in the preparation of the text.

CHAPTER 2

SILVICULTURAL PRACTICES AND EROSION POTENTIALS

Erosion is a natural phenomenon. It is the process which gradually removes soil and rock from a site by various agents including wind and water; in the case of mass wasting, gravity is the major agent. The rate of erosion is the consequence of physical site characteristics, biotic features and the hydrologic cycle. These include the type of soil materials, topography, macro- and micro-climatic conditions and the density and distribution of vegetation. The observed rate of erosion results from the interaction of all these factors.

Man's activities often disrupt this complex interaction. In the case of silviculture, this might occur by removing the protective cover of trees, thus exposing the forest floor to the erosive energy of precipitation. Two related but distinct concepts need to be discussed in terms of surface erosion--erosion potential and erosion hazard. Both are pertinent to evaluating silvicultural management systems.

Erosion hazard is directly associated with physical site characteristics. Energy from radiation, precipitation, gravity or flowing water provides the effective force for erosive action. In forested environments energy inputs are dissipated by the vegetative cover or the litter layer, for example. The degree to which a site could respond, in the absence of these modifying agents can be viewed as the erosion hazard. The erosion potential is the extent to which management activities affect the modifying factors or site characteristics themselves. Thus, erosion hazard is an inherent property of the site while erosion potential relates to the effect of silvicultural activities upon that site.

It becomes clear that the relationships between rate of erosion and silvicultural activities are complex and depend upon various environmental conditions and the extent or intensity of silvicultural actions. In the following discussion attention is focused on erosion hazard in a regional context and erosion potential in terms of various activities.

. . . .

Relating the various environments occurring throughout the United States to silvicultural management requires an aggregation of information to a manageable scale. Such information has been prepared by Bailey (1976) in the form of a map which organizes and interprets inventories of the Nation's lands and resources, taking into account both biotic (flora and fauna) and abiotic (climate, soils and land-surface form) factors. The map delineates "ecoregions" which are similar with respect to broad ranges of environmental parameters. Bailey's format provides a convenient basis for discussing both erosion potential and erosion hazard, for identifying vegetation types, and for discussing related silvicultural activities.

The ecoregion descriptions appearing on the map pages have been largely adapted from Bailey's classifications that appear in Ecoregion Descriptions (To Accompany Map of Ecoregions of the United States) (in press). Some areas in the continental United States were not characterized (the Mojave-Sonoran desert south of the Rocky Mountains, for example) because little or no silvicultural activity takes place. Descriptions of some factors (fauna, for example) that Bailey considers were not included, again because they are not directly pertinent to a discussion of non-point pollution abatement, or to silvicultural activities in general.

The use of ecoregions or the ecoregion system does not imply that this is the only applicable land classification system. Bailey's ecoregion system is relatively new and largely untested in an operational sense. However, since erosion response to silvicultural activities arises from the complex interaction of many environmental factors, it was concluded that a classification system that encompasses this concept should be employed.

The remainder of this chapter is structured around seven major ecoregions. Each is discussed separately. Included is a map which delineates the areal extent of the ecoregion together with a brief narrative describing the major characteristics related to the environment and silviculture.

In addition to the map and its narrative, a table is presented which relates each major silvicultural type within the ecoregion to harvesting paractice, logging system, slash disposal, intermediate cultural treatment, and access. Each element of the array contains a brief summary of the individual practices which are currently being employed. For example, the currently applied methods for slash disposal in the white pine type would be noted, along with an indication of the frequency or generality of use. The information contained here is not intended to be prescriptive, but reflects the current situation. Little silvicultural activity occurs in Ecoregion 2500. For this reason, no table for Major Silvicultural Activities and Access Practices in Ecoregion 2500 has been included. Refer to adjacent areas for required information.

Access activities are only indirectly related to specific forest types. However since these activities are closely correlated with geographic characteristics and harvesting activities/cultural treatments, a discussion of common access practices typical of the ecoregion itself is included in each table.

A summary of silvicultural techniques is presented at the bottom of the table to provide a short review of the information contained above. Major activities are emphasized.

The principal basis for presenting the information on current silvicultural methods is to indicate where problems of erosion might arise, not to identify "best management practices." This objective is accomplished by using a scale which indicates the relative severity of erosion potential for these activities. Silviculture activities are ranked relative to themselves, not in comparison to other erosion-causing activities like construction or agriculture, for instance. Similarly, the indications for erosion potentials relate to the ecoregion only--not to comparisons between ecoregions. Dark green highlighting is used to signify an activity or practice that could present significant erosion problems; light green highlighting denotes a somewhat lower or moderate potential. The lack of color highlighting is an indication that little or no erosion potential should generally be expected.

The purpose of this technique is to emphasize where problems could arise in the application of silvicultural management, rather than to indicate where problems presently occur. Similarly, specification of high erosion potential for an activity does not preclude the opportunity for mitigation to the extent that the activity may have little or no erosion impact. The inherent variability of environmental conditions within any ecoregion is large. Combined with the range of alternative management strategies which can alter these conditions, the task of producing a quantitative, objective estimate of erosion impacts is substantial--especially at the indicated geographic scale.

The reader must not reach unwarranted conclusions from the information presented on erosion potentials. For example, clearcutting is often rated as having a relatively high erosion potential when compared with selection cutting. The conclusion that selection should be preferred over clearcutting as an erosion reduction practice need not follow. There are other factors to take into account. For example, the regeneration prescription for the desired forest type may require even-aged management as opposed to uneven-aged. Second, when considered with other management goals, the harvest system should be economically efficient--just as clearcutting often is. Third, openings caused by smaller clearcuts or selection cuttings may require a more extensive road network--often identified as a major source of erosion. Trade-offs between reduced harvest impact and access impacts must be included in the evaluation. In perspective, the erosion potential specification is only to identify and focus on possible problems rather than mandate changes in management.

The premise for evaluating the various activities in terms of the potential scale included a number of factors: Field surveys were conducted to sample activities in each ecoregion. Forestry researchers from both private industries and public agencies were consulted for information about current practices and problem areas. As a result, the scaling is a reflection of judgment based on present knowledge and the expertise of many individuals.

A detailed literature search on the state-of-the-art status of silviculturally-related erosion knowledge was not conducted due to the existence of several current sources (for example, the EPA reports, Forest Harvest, Residue Treatment, Reforestation & Protection of Water Quality, 1976 and Non-point Water Quality Modeling in Wildland Management: A State-of-the-Art Assessment (Volume I--Text) 1977.

A concluding paragraph is presented at the bottom of each table which reviews erosion potentials that arise from silvicultural management in each ecoregion. This review discusses the major practices which contribute to erosion potentials and indicates the individual activities that contribute to the rating. Again, this information comes from a diversity of sources.

To provide quantitative assessments of which silvicultural operations create greater erosion potentials is beyond both the purpose and scope of this report. Most erosion potentials created by silvicultural operations are site-specific and should be dealt with on a site-specific basis. When applied to specific situations, general rules will frequently be unworkable, ineffective, or both. Hence, this report is not intended to present blueprints, but to identify problems. Solutions to these problems will require the planner and forest manager to apply their experience and ingenuity to specific sites.

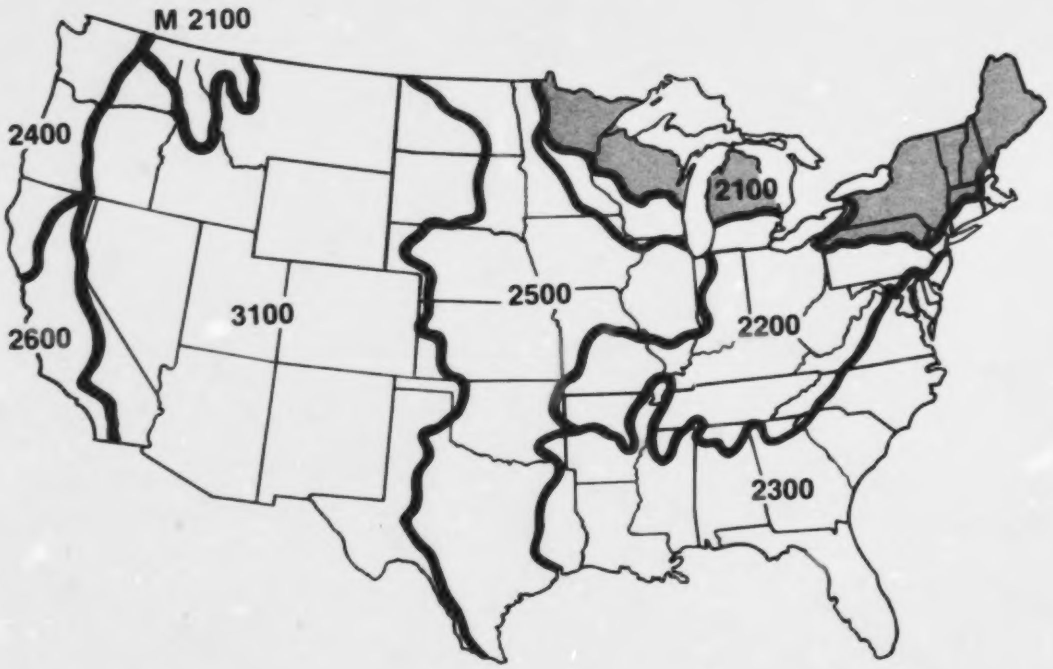

Figure 2. Ecoregion 2100 (After Bailey 1976).

HUMID WARM-SUMMER CONTINENTAL (LAKE STATES AND NORTHEAST)

This region occupies about 367,800 square miles, or 11.1 percent, of the total land mass in the United States. Most of the area has low relief, but rolling hills and low mountains occur in many places. Lakes, poorly drained depressions, morainic hills, outwash plains, and other glacial features are characteristic as a result of Pleistocene glaciation. Elevations range from sea level to 4,000 feet with a few isolated peaks of more than 5,000 feet.

Polar continental air masses on the north and maritime or continental tropical air masses on the south create strong seasonal temperature contrasts. There are four to eight months of over 50° F. The warm summer has an average temperature in which the warmest month is below 71.6° F. Rainfall is ample at all times, but distinctly greater during the summer.

Soils vary greatly from place to place and include peat, marl, clay, silt, sand, gravel, boulders and various combinations of these materials. Alfisols and Spodosols (Podzols) are strongly leached but with an upper layer of humus. Cool temperatures inhibit bacterial activity which would normally destroy organic matter in tropical regions; these soils are deficient in calcium, potassium, and magnesium and are, in general, acid in chemical nature. These are not highly productive for crop farming, but well suited to the growth of conifers.

Conifer and mixed conifer deciduous forest extend throughout the ecoregion. Vegetation is characterized as "transitional" between the boreal forest and deciduous forest zone. Forests are made up of either mixed stands of a few coniferous species, or an arrangement in which pure deciduous forest exists where there is a favorable habitat and good soils, and pure coniferous forest exist on less favorable habitats with poor soils.

TABLE 2. MAJOR SILVICULTURAL ACTIVITIES AND ACCESS PRACTICES IN ECOREGION 2100 (LAKE STATES AND NORTHEAST).

SILVICULTURAL TYPE	HARVESTING ACTIVITIES		CULTURAL TREATMENTS				ACCESS	
	HARVESTING PRACTICES	LOGGING SYSTEMS	SLASH DISPOSAL	SITE PREPARATION	STOCKING CONTROL	OTHER	TEMPORARY ROADS	PERMANENT ROADS
Allegheny hardwoods	Two regeneration systems are used, clearcutting and shelterwood. Size of cutting blocks range from 21 to 50 acres. Commercial thinnings are made. Major species are black cherry, sugar and red maples, and yellow poplar. Associate species are white ash, birches, beech, and hemlock.	Crawler tractors with steel tracks and rubber-tired skidders are used. Felling is done with chain saws. Log storage on cutting areas is of short duration.	Slash disposal is done along roads for aesthetic purposes. Slash is moved away from the road a prescribed distance or lopped and scattered, or logging is not done on roadside.	Hand tools such as chain saws, axes, and brush hooks are used. A small amount of herbicide application is done in spots where planting is by hand, herbicides are applied with injectors.	Precommercial thinning is done with chain saws. No release work is done.	None	Many temporary roads on private timber lands have no planned design or construction. Roads vary in width from 8 to 12 feet and seldom are provisions made for turnouts. These roads are generally located where the least effort and construction are involved. The two most widely used drainage structures are water bars and metal pipe. The drainage pipes are usually removed when harvesting and cultural treatments are completed. Generally, this class of road is not surfaced, however, wet spots are sometimes graveled to provide a firm road bed. Many roads built as temporary have become permanent. Some have poor location and design. An exception to the usual practice is found in the far northern latitudes where access must be provided across extensive flat areas of unstable material such as peat muskeg or lowland swamps. Access is often limited to frozen roads requiring clearing, but negligible cut and fill. Many temporary roads are left for natural revegetation. Where this is inadequate, there is a trend for seeding, fertilizing, and even mulching. When these roads are left open, many times they are used for trail riding. When properly closed or obliterated, this traffic and erosion source is eliminated. On flat to rolling terrain, road grades seldom exceed 7 percent. Road grades on hilly to mountainous terrain are generally less than 10 percent, however, some short sections may be as high as 20 percent.	Generally, most permanent roads on private timber lands are constructed without adequate planning and design. However, high quality, permanent roads on private lands are being constructed increasingly, whenever cable logging and chipping systems are used. Road density will average from one to three miles per square mile, and increases with steep topography. Most roads are not designed for speed, but are located for ease of construction. The designed speed is seldom greater than 10 mph. The typical road is single-lane with 10-foot running surface, and the turnouts are located at convenient points. Cut and fills are held to a minimum, except long fills are common in flat and poorly drained areas. Usually, surface water is removed by parallel ditches and culverts. Cross drainage is accomplished by permanent structures. Gravel surfacing is used only when needed for structural support of wheel loads. Road grades vary from 0-10 percent, with occasional pitches up to 20 percent. Bare cut-and-fill slopes are generally seeded to grass and fertilized. Traffic on timber roads is limited to management activities; however, in cases of absentee ownership, these may be used for recreational purposes.
Jack pine	Regeneration cutting systems used are clearcutting, seed tree, and shelterwood. Size of cutting blocks range from 21 to 200 acres. Some clearcutting is done in strips to get natural seeding from the uncut strips. Associate species are red and white pines, aspen, paper birch, oaks, and spruce. Jack pine is also found in pure stands.	Crawler tractors with steel tracks and rubber-tired skidders are used. Felling is done with chain saws and feller-bunchers. Log storage on cutting areas is of short duration.	Slash disposal is done by broadcast burning, lop and scatter, and chopping.	Broadcast burning is extensively used to prepare the site. Some machine planting with continuous scalping is practiced in clearcut areas. Clearcut areas are either machine planted, aerial seeded or naturally seeded. Where the seed tree and shelterwood systems are used, mechanical scarification is common.	None	Insect and disease control is by harvesting.		
Red and white pine	Clearcutting and shelterwood are the regeneration cutting systems used. Size of cutting blocks range from 21 to 50 acres. Commercial thinnings are made. Associate species are jack pine, aspen, paper birch, red maple, northern red oak, and white spruce-balsam fir mixtures.	Rubber-tired skidders and crawler tractors with steel tracks are used. Felling is done with chain saws. Log storage on cutting areas is of short duration.	Logging debris is broadcast burned or lopped and scattered.	Site preparation is done by machine scarification for hand planting.	Release of red pine seedlings is done by aerial spraying of herbicides. No precommercial thinning is done.	None		
Aspen	Clearcutting is the only regeneration cutting system used. Size of cutting blocks range from 21 to 100 acres. Associate species are paper birch, jack pine, balsam fir, maples, and northern red oak.	Rubber-tired skidders and crawler tractors with steel tracks are used. Felling is done by chain saws and feller-bunchers. Log storage on cutting areas is of short duration.	Slash is commonly not disposed of; where it is, slash is lopped and scattered.	Site preparation is done by hand tools such as chain saws, axes, and brush hooks. Regeneration from root suckers is natural.	None	None		
Paper birch	Clearcutting is the only regeneration cutting system used. Size of cutting blocks range from 21 to 50 acres. No commercial thinning is done. Associate species are aspen, spruce-fir, and red pine.	Rubber-tired skidders and crawler tractors with steel tracks are used. Felling is done with chain saws. Log storage on cutting areas is of short duration.	None	None	None	None		
Black spruce, upland	Clearcutting is the only regeneration cutting system used. Size of cutting blocks range from 21 to 50 acres. Commercial thinning is done. Associate species are black ash, red maple, aspen, paper birch, pines, and white spruce.	Rubber-tired skidders and crawler tractors are used. Felling is done by chain saws. Log storage on cutting areas is of short duration.	Slash is disposed of by broadcast burning.	Machine scarification is used for natural regeneration by seeding unless broadcast burning exposes mineral soil.	Release work is done by aerial spraying of herbicides. Precommercial thinning is very seldom done.	None		
Black spruce, lowland	Clearcutting is the only regeneration cutting system used. Size of cutting blocks range from 21 to 50 acres. No commercial thinning is done. Associate species are tamarack, white cedar, balsam fir.	Rubber-tired skidders are used. Winter logging roads permit use of crawler tractors also. Felling is done by chain saws. Log storage on cutting areas is of short duration.	Slash is disposed of by broadcast burning.	Broadcast burning of slash is required for seedbed preparation.	None	None		

(continued)

TABLE 2 (continued)

SILVICULTURAL TYPE	HARVESTING ACTIVITIES		CULTURAL TREATMENTS				ACCESS	
	HARVESTING PRACTICES	LOGGING SYSTEMS	SLASH DISPOSAL	SITE PREPARATION	STOCKING CONTROL	OTHER	TEMPORARY ROADS	PERMANENT ROADS
Spruce-fir	The only regeneration cutting system used is shelterwood Size of cutting blocks range from 6 to 20 acres Commercial thinnings are made Major species are red and white spruce & balsam fir. Associate species are white cedar, white pine, red maple paper birch and aspen	Rubber-tired skidders and crawler tractors are used Felling is done by chain saws Log storage on cutting areas is of short duration	Disposal of slash is by lopping and scattering	None	None	None		
Spruce-hardwood	Two regeneration cutting systems are used, clearcutting and shelterwood. Size of cutting blocks range from 21 to 50 acres Commercial thinning is done Major species are red spruce, yellow birch, beech, and sugar maple Associate species are white cedar, balsam fir, black ash, red maple, aspen, and paper birch	Rubber-tried skidders and crawler tractors are used Felling is done by chain saws Log storage on cutting areas is of short duration	None	None	None	None		
Maple-beech-birch	Regeneration cutting systems used are clearcutting and single-tree and group selection Size of cutting blocks range from 21 to 50 acres Commercial thinnings are made Major species are sugar maple, American beech, and yellow birch Associate species are hemlock, beech, basswood balsam fir, elm, white pine and white ash	Rubber-tired skidders and crawler tractors are used Felling is done by chain saws Log storage on cutting areas is of short duration	None	None	Precommercial thinning is done by chain saws and axes Release is done by chain saws	None		
Oak or Lowland hardwoods	Three regeneration cutting systems used are clearcutting, shelterwood and group selection Size of cutting blocks range from 51 to 100 acres Commercial thinnings are made. On the oak type primary species are red and white oak Primary species on the lowland hardwood type are a composite of wet site species such as black ash, American elm and red maple There are many associate cies of the two types named including aspen, ash, maples, white pine, jack pine, basswood, elm, boxelder, and maples	Rubber-tried skidders and crawler tractors with steel tracks are used Felling is done by chain saws Log storage on the cutting areas is of short duration	Disposal of slash is by lopping and scattering	Chain saws, axes, and brush hooks are used for natural regeneration	Precommercial thinning is done by chain saws No release work is done There is no precommercial thinning done on lowland hardwoods	None		

SUMMARY OF HARVESTING ACTIVITIES AND CULTURAL TREATMENTS

Clearcutting is the primary method of regeneration cutting used, although the seed-tree and shelterwood methods are also employed Both even- and uneven-aged management is practiced Rubber-tired skidders and crawler tractors with steel tracks are used to move logs to log landings Increasingly however both private and state foresters are using the cable logging system in both steep and swampy areas The skyline system is being used in the mountain terrain and highlead system is being used in low and swampy places Felling is done primarily with chain saws and to a lesser extent with feller bunchers Logs are stored on log landings for very short periods of time Slash disposal is done in some areas for fire protection and as part of the site preparation work

Site preparation is done by machines, broadcast burning, and hand tools Regeneration is artificial for jack and red pine with some natural seeding Almost all of the hardwood regeneration is by natural methods Release work is done by aerial application of herbicides and hand tools Precommercial thinning is doen by hand tools Insect and disease control work is very minor

EROSION POTENTIAL CODE

▨ INDICATES GREATEST EROSION POTENTIAL

☐ INDICATES MODERATE EROSION POTENTIAL

☐ INDICATES LOW EROSION POTENTIAL

ECOREGION 2100: HUMID COOL-SUMMER CONTINENTAL (LAKE STATES AND NORTHEAST)

EROSION HAZARDS AND POTENTIALS

Slopes varying from flat to moderate, moderately erosive soils with few areas subject to mass wasting, and moderate moisture conditions are characteristic of this ecoregion Surface erosion hazard is low in the north where flat slopes and well-drained glaciated materials are found In the south materials are more silty and where it occurs on steeper slopes, surface erosion hazard is moderately high In steep areas the erosion potential is less when using the skyline system than when using the common ground skidding systems Mass wasting hazard is low throughout the ecoregion

The diversity of timber types and the resultant complexity of management techniques produce a variety of erosion potentials In general, access activities are considered the greatest erosion potentials This, of course, depends greatly upon the topography The activity is often the result of the harvesting system used, although in this ecoregion an extensive road network already exists throughout the many areas Relative magnitude of erosion potentials arising from harvesting and cultural treatments depends largely upon the intensity of management Where natural regeneration is used, characteristically in many of the hardwood types, cultural activities are minimal Where extensive site preparation is employed, these activities may present a greater potential than harvesting activities

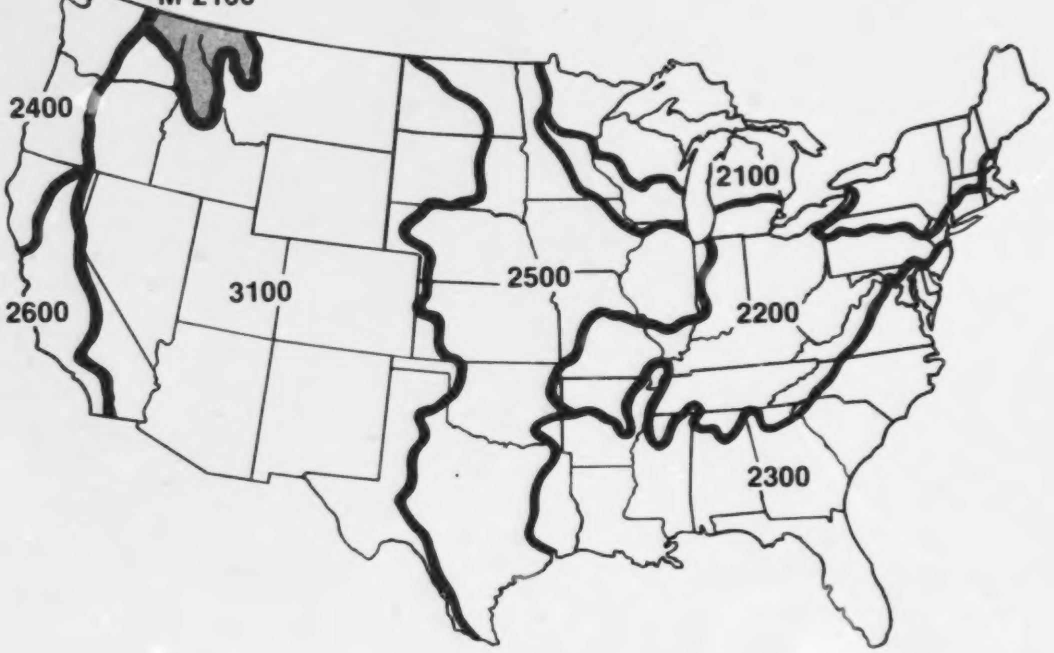

Figure 3. Ecoregion M2100 (After Bailey 1976).

HUMID WARM-SUMMER CONTINENTAL (COLUMBIA FOREST)

The Columbia forest occupies about 45,300 square miles, or 1.4 percent, of the total land mass in the United States. It consists of steep rugged mountains which rise to over 9,000 feet and have local relief in excess of 3,000 feet. Most of the region has been glaciated.

This ecoregion is characterized as a "highland" province, separate from that of Ecoregion 2100 (Lake States and Northeast). It represents a special problem in classification in that, as with all mountain regions, the middle and upper slopes do *not* have the same climate as their adjacent lowlands; however, they do have the same climatic regime as the lowlands. In this particular warm-summer continental region having a humid climatic *regime*, valley bottoms are humid and the montane zone is the lowest zone present. The coldest month is below 32°F and warmest is below 71.6°F. Rainfall is adequate throughout the year, but summer tends to be dry because Westerly air masses bring the summer dry climate of the Pacific Coast inland across the area. The effect is a distinct climatic gradient from both north to south and east to west.

Soils are Alfisols, Spodosols, and Inceptisols. A variety of igneous, sedimentary and metamorphic rocks form mountain masses. In comparison with other parts of the Rocky Mountains, however, shallowness and stoniness of soils play a relatively minor part in forest distribution. In the foothills of the Rockies and to the south of the glacial borders, loess and volcanic ash have been deposited on the slopes, thus helping to form the soils.

Effect of the climatic gradient in this region is reflected in both the flora and vegetation types. Mixed coniferous-deciduous forest predominates, with Douglas-fir forest and cedar-hemlock-Douglas-fir forest being the major forest types.

TABLE 3. MAJOR SILVICULTURAL ACTIVITIES AND ACCESS PRACTICES IN ECOREGION 2100 (COLUMBIA FOREST)

SILVI-CULTURAL TYPE	HARVESTING ACTIVITIES			CULTURAL TREATMENTS			ACCESS	
	HARVESTING PRACTICES	LOGGING SYSTEMS	SLASH DISPOSAL	SITE PREPARATION	STOCKING CONTROL	OTHER	TEMPORARY ROADS	PERMANENT ROADS
Larch-Douglas-fir	Practices are limited to regeneration cuts of shelterwood and some seed tree cutting Associate species are Douglas-fir, western hemlock, western red cedar, grand fir and subalpine fir	Either crawler tractor or rubber-tired skidder are used on slopes up to 40 percent, occasionally to 50 percent on private lands. Short-span ground skid or partial suspension cable systems are commonly used on steeper slopes and unstable soils. Tractors and skidders are used interchangeably	Pile and burn is the common disposal method in shelterwood cuts. YUM yarding is also used in shelterwood A combination of broadcast burn and pile and burn is used in seed tree cuts	Natural regeneration with no special site preparation is used in shelterwood Seed tree cuts are scarified through skidding, slash disposal, or other treatment for natural regeneration	Some precommercial thinning takes place, with little, if any, slash disposal	None	Temporary roads are used primarily on the flatter slopes in conjunction with tractor tree removal systems. These roads may be constructed on any cross slope, but the majority are on relatively gentle cross slopes of from 15 to 35 percent. Road density is too variable to establish an average Lack of design and construction control allows the width to vary greatly from 10 to 20 feet, with the average about 18 feet. Turnouts are seldom constructed and cut slopes are usually vertical. The surface is drained primarily with water bars and occasionally with drainage dips. Cross drainage structures are temporary Temporary road surfaces are of native material. Road grades are normally between 2 and 5 percent with occasional pitches to 15 percent. Vegetation is established on bare areas by the application of grass seed and fertilizer Temporary roads are returned to resource production when tributary timber has been removed. Usual treatment is to remove temporary drainage structures, cut slopes and scarify the driving surface, construct additional water bars, and seed and fertilize the bare areas. Access points are physically blocked Many temporary roads were built in the past, some being returned to production and some not. Present practice is to build properly located, designed and constructed permanent roads whenever future need is anticipated, thereby substantially reducing or eliminating temporary road density	Permanent road densities vary from 5 to 7 miles per square mile, with tractor skidding on flatter slopes requiring the greater mileage Roads are constructed on side slopes from 0 to 100 percent with the majority of the mileage built on slopes between 35 and 60 percent. The typical permanent road is single lane, with turnouts, and a 12-foot running surface. Parallel ditches and culverts drain the surface. Cross drainage is accomplished by use of permanent structures. Design speeds are most often 10 mph or less Variations in construction include eliminating the parallel ditch through sections of more stable material, outsloping and constructing drainage dips on the flatter cross slopes, or insloping and installing culverts on the the steeper cross slopes. On cross slopes greater than 55 or 60 percent, the entire road surface is benched into the hillside, with excess material hauled to an appropriate disposal site. Gravel surfacing is not normally applied Usual permanent road grades are between 7 and 10 percent, with pitch grades as high as 15 percent. Grass seed and fertilizer is applied to cut-and-fill slopes and ditches. Mulch is added on steeper slopes. There is a trend towards closing permanent roads to public use When timber is harvested on slopes over 30 to 40 percent, trees are removed from the site by one of the shorter span cable systems
Ponderosa pine	Common practices are selection and shelterwood, some clearcutting in 2 to 20 acre blocks Ponderosa pine often occurs in pure stands. Associate species are lodgepole pine, Douglas-fir, white fir and larch	See larch-Douglas-fir type	Machine pile and burn is used in tractor/skidder shelterwood cuts; lop and scatter and swamper burn in cable areas In selection cuts, piling and burning and lop and scatter are common In clearcuts, swamper burn, pile and burn, and some YUM yarding is used	In shelterwood, scarification is done through logging, slash disposal or other means, and normally planted Hand interplanting is common in selection cuts Following slash disposal, clearcuts are hand or machine piled	See larch-Douglas-fir type	None		
Grand fir	Practices are limited to regeneration cuts of clearcut and shelterwood. Clearcuts average 35 acres The most common associate species is western white pine	Tractors or skidders are used for both clearcutting and shelterwood on slopes to 40 percent, occasionally to 50 percent on private lands. Short-span ground skid or partial suspension cable systems are commonly used on slopes over 40 percent or on unstable wet soils	Disposal in shelterwood cuts is normally pile and burn, with YUM yarding Clearcuts are commonly broadcast burned but occasionally machine piled and burned	Normal harvesting activities provide sufficient preparation for natural reproduction Following broadcast burn, clearcuts are hand planted	None	None		
Hemlock-cedar	Clearcutting in blocks of 20 to 50 acres is the only predominant harvest practice Associate species are white pine, Douglas-fir, grand fir	Tractors or skidders are used on slopes to 40 percent. Cable ground skids are used on steeper, dry, stable soils. Cable-partial suspension systems are used on steeper, wet, less stable soils	Tractor areas are machine piled and burned. Cable areas are broadcast burned	Natural regeneration is expected, but to insure success, hand planting usually follows slash disposal	None	None		
White pine	Clearcutting in blocks of 20 to 50 acres is the predominant harvest practice. Selection cutting is also practiced in those stands where adequate stocking of immature timber is present Associate species are larch, lodgepole pine, Douglas-fir, grand fir, western red cedar, western hemlock, Engelmann spruce, and subalpine fir	In clearcut areas tractor/skidder, cable ground skid, cable-partial suspension and occasionally helicopter are used. In selection cut areas, tractor/skidder, cable-ground skid and cable-partial suspension systems are used	Clearcuts are typically broadcast burned, but may be frequently machine piled and burned Tractor or skidder selection cut areas are machine piled and burned. Cable areas are hand piled and burned. Where defect is high, YUM yarding is done in all selection areas	Clearcuts are hand planted after slash disposal	None	All phases of blister rust control program abandoned		
Spruce-subalpine fir	Clearcutting in blocks of 20 to 50 acres is the only harvest practice Associate species are lodgepole pine and aspen	See hemlock-cedar type	See hemlock-cedar type	See hemlock-cedar type	None	None		
Lodgepole pine	Clearcutting in blocks of 20 to 50 acres is the only harvesting practice used Lodgepole pine occurs in pure stands	Crawler tractors or skidders are used on slopes to 30 percent. Lodgepole is not normally found on steeper slopes, but where it does occur it is generally not harvested	Slash is broadcast burned or machine piled and burned	Skidding, burning, or machine piling provide preparation and/or scarification for natural reproduction to take place	See larch-Douglas-fir type	None		

SUMMARY OF HARVESTING ACTIVITIES AND CULTURAL TREATMENTS

Clearcutting in average blocks of from 20 to 50 acres is the predominant harvesting practice although on some silvicultural types, shelterwood, selection and, in places, seed-tree cutting takes place. Throughout the ecoregion the logging system on slopes of up to 40 percent is by crawler tractor or rubber-tired skidder used interchangeably. Cable ground skids are common on the steeper, dry, stable soils; cable-partial suspension systems are used on the less stable soils. Slash disposal is closely tied to both harvesting and logging; in this region a wide range of disposal methods — including lop and scatter, swamper burning and YUM yarding — is used, although machine pile and burn and broadcast burn are the most frequent.

On a few silvicultural types, site preparation involves hand or machine planting, but natural revegetation is expected on most of the types; often it involves no special site preparation other than that accomplished through the logging operation and slash disposal. Very little stocking control is practiced; there is some precommercial thinning, however, on a few types.

EROSION POTENTIAL CODE

☐ INDICATES GREATEST EROSION POTENTIAL

☐ INDICATES MODERATE EROSION POTENTIAL

☐ NDICATES LOW EROSION POTENTIAL

ECOREGION 2100: HUMID WARM-SUMMER CONTINENTAL (COLUMBIA FOREST)

EROSION HAZARDS AND POTENTIALS

Steep slopes, unstable soils and seasonally high moisture conditions are characteristic of this ecoregion. Both surface and mass erosion potential are high, contributing to high erosion potential from silvicultural operations. Local variations in land type and precipitation pattern contribute to variance within the ecoregion. The primary erosion potentials arise from access activities including location, design, construction and maintenance. Temporary roads have the greatest potential. The access system, however, is dictated by the choice of logging system. Erosion potentials from harvesting activities are rated as moderate impacts. Slash disposal and skidding activities contribute to this rating. Site preparation consists of the greatest potential from cultural activities, which ranks relatively low.

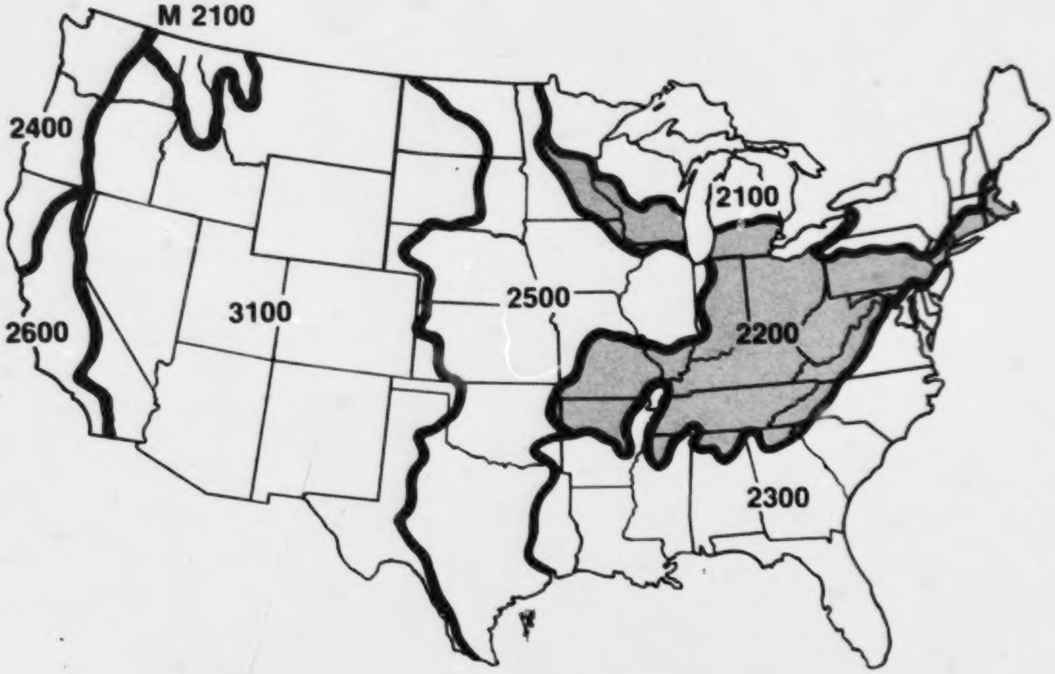

Figure 4. Ecoregion 2200 (After Bailey 1976).

HUMID HOT-SUMMER CONTINENTAL

This region occupies about 367,800 square miles, or 11.1 percent of the total land mass in the United States. The land-surface form in this region is rolling, though some parts are nearly flat; in the Appalachian Mountains there is high relief up to 3,000 feet. The northern areas have been glaciated, but not the southern.

This ecoregion shares the same characteristics as Ecoregion 2100 except it is more moderate with a strong annual temperature cycle and cold winters and a hot summer; the warmest month is above 71.6°F. Precipitation is markedly greater in summer months. Because temperatures are warm, the soils are rich in humus and moderately leached.

Soils are Alifsols, Spodosols and Inceptisols. They are rich in humus and moderately leached as to have a distinct, light-colored leached zone.

Forest vegetation is deciduous, with a dense canopy in summer which produces a thick litter layer. Lower layers of small trees and shrubs are not well developed. Common trees of the deciduous forests are oak, beech, birch, hickory, walnut, maple, basswood, elm, ash, tulip tree, sweet chestnut and hornbean. In the more poorly drained habitats, the deciduous forest consists of such trees as alder, willow, ash and elm and many shrubs. Pines readily develop as second-growth vegetation where the forests have been cleared.

TABLE 4. MAJOR SILVICULTURAL ACTIVITIES AND ACCESS PRACTICES IN ECOREGION 2200

SILVI-CULTURAL TYPE	HARVESTING ACTIVITIES		CULTURAL TREATMENTS				ACCESS	
	HARVESTING PRACTICES	LOGGING SYSTEMS	SLASH DISPOSAL	SITE PREPARATION	STOCKING CONTROL	OTHER	TEMPORARY ROADS	PERMANENT ROADS
Yellow pine ···	Two regeneration cutting systems are used — clearcutting and seed tree Size of cutting blocks range from 10 to 50 acres Commercial thinnings are made Associate species are oaks, hickories, and yellow poplar	Rubber-tired skidders and crawler tractors with steel tracks are used Felling is done with chain saws Log storage on cutting areas is of short duration	None ··········	Machine clearing and piling in windrows is used, and hand tools such as chain saw, axe, or tree injector are used when hand tree planting is done Machine scarification is done where natural seeding will occur	Precommercial thinning is done by machine and hand tools Release is done by hand tools	Control of southern pine beetle is done by harvesting and by use of pesticides	Many temporary roads on private timber lands have no planned design or construction Roads vary in width from 8 to 12 feet and seldom are provisions made for turnouts These roads are generally located where the least effort and construction are involved The two most widely used drainage structures are water bars and metal pipes The drainage pipes are usually removed when harvesting and cultural treatments are completed Generally, this class of road is not surfaced, however, wet spots are sometimes graveled to provide a firm road bed Many roads built as temporary have become permanent Some have poor location and design An exception to the usual practice is found in the far northern latitudes where access must be provided across extensive flat areas of unstable material such as peat muskeg or lowland swamps Access is often limited to frozen roads requiring clearing but negligible cut and fill Many temporary roads are left for natural revegetation Where this is inadequate, there is a trend for seeding, fertilizing, and even mulching When these roads are left open, many times they are used for trail riding When properly closed or obliterated, this traffic and erosion source is eliminated On flat to rolling terrain, road grades seldom exceed 7 percent Road grades on hilly to mountainous terrain are generally less than 10 percent, however some short sections may be as high as 20 percent	Generally, most permanent roads on private timber lands are constructed without adequate planning and design However, high quality, permanent roads on private lands are being constructed increasingly, whenever cable logging and chipping systems are used Road density will average from one to three miles per square mile, and increases with steep topography Most roads are not designed for speed, but are located for ease of construction The designed speed is seldom greater than 10 mph The typical road is single-lane with a 10-foot running surface and the turnouts are located at convenient points Cut and fills are held to a minimum, except long fills are common in flat and poorly drained areas Usually, surface water is removed by parallel ditches and culverts Cross drainage is accomplished by permanent structures Gravel surfacing is used only when needed for structural support of wheel loads Road grades vary from 0 to 10 percent, with occasional pitches up to 20 percent Bare, cut-and-fill slopes are generally seeded to grass and fertilized Traffic on timber roads is limited to management activities, however, in the case of absentee ownership, these may be used for recreational purposes
Virginia pine	The only regeneration cutting system is clearcutting Size of cutting blocks range from 6 to 20 acres Commercial thinnings are made Associate species are shortleaf pine, oaks, and hickories	Rubber-tired skidders and crawler tractors are used Felling is by chain saw In some areas, four-wheel farm tractors and small machines are occasionally used along roadside areas Log storage on cutting areas is of short duration	None ··········	Hand tools such as chain saw, axe, tree injection for residual hardwoods, felling by axe and chainsaw, hand planting and tree injectors are used to prepare sites for hand tree planting	Release work is done by hand tools No precommercial thinning is done	Control of southern pine beetle is done by harvesting and very occasionally by use of pesticides		
White pine ····	The regeneration cutting systems used are clearcutting and shelterwood Size of cutting blocks range from 10 to 50 acres Commercial thinnings are made Associate species are shortleaf or Virginia pines, oaks, hickories, yellow poplar, black cherry, and hemlock	Rubber-tired skidders and crawler tractors with steel tracks are used Felling is done by chain saws Log storage on cutting areas is of short duration	Slash disposal is rare, although lop and scatter are occasionally practiced	Hand tools such as chain saw, ax, and tree injector are used to prepare sites for hand tree planting Some stripping is done with the bulldozer to prepare a lane in which trees are planted	Release work is done by hand tools No precommercial thinning is done	Control of blister rust is by selection of low hazard zones for planting, white pine weevil is controlled by establishing a light overstory		
Oak-hickory or Upland hardwood or Cove hardwood	Clearcutting, shelterwood and group selection are the main regeneration cutting systems used Size of cutting blocks range from 10 to 50 acres Commercial thinnings are made Associate species are white pine, hemlock, shortleaf pine, yellow poplar, ash, cherry, blackgum, and redgum	Rubber-tired skidders and crawler tractors with steel tracks are used Felling is done by chain saws Log storage on cutting areas is of short duration	None ··········	Hand tools such as chain saw, ax, and tree injector are used for natural regeneration	Precommercial thinning is done with hand tools	None		

SUMMARY OF HARVESTING ACTIVITIES AND CULTURAL TREATMENTS

Clearcutting is the primary regeneration cutting system, although the seed-tree and shelterwood systems are also used. Even-aged management is practiced. Rubber-tired skidders and crawler tractors with steel tracks are the two primary logging systems used. Increasingly, however, both private and state foresters are using cable logging in both steep and swampy areas. The skyline system is being used in the mountainous terrain and highlead system is being used in low and swampy places. Felling is done with chain saws. Log storage on cutting areas is of short duration. No slash disposal is done.

Most pine regeneration is artificial with site preparation by machine or hand tools for hand tree planting. Some machine scarification is done for seed tree areas. All hardwood regeneration is natural with site preparation by handtools. Release is done in the pine types, precommercial thinning is done mainly in the hardwood types. Southern pine beetle control work is done by harvesting and use of pesticides.

EROSION POTENTIAL CODE

☐ INDICATES GREATEST EROSION POTENTIAL

☐ INDICATES MODERATE EROSION POTENTIAL

☐ INDICATES LOW EROSION POTENTIAL

ECOREGION 2200:
HUMID HOT — SUMMER CONTINENTAL

EROSION HAZARDS AND POTENTIALS

Moderate slopes in the Midwestern states increase to steep in the mountains of the East, moderate moisture conditions, and erosive soils subject to mass wasting are characteristics of this ecoregion. Both surface erosion and mass wasting potential and hazard vary from fairly low to high, increasing with the steepness of the topography. In steep areas, the erosion potential is less when using the skyline system than when using the common ground skidding systems. In steep or mountainous topography access activities contribute to the greatest erosion potential although the amount of this activity directly related to silvicultural management may be minimal due to the already existing transporation network. When access networks result from silvicultural operations, these are usually functionally related to the harvesting system employed. Where artificial regeneration on intensively site-prepared areas indicate intensive management techniques, the cultural treatments may present the greatest erosion potentials.

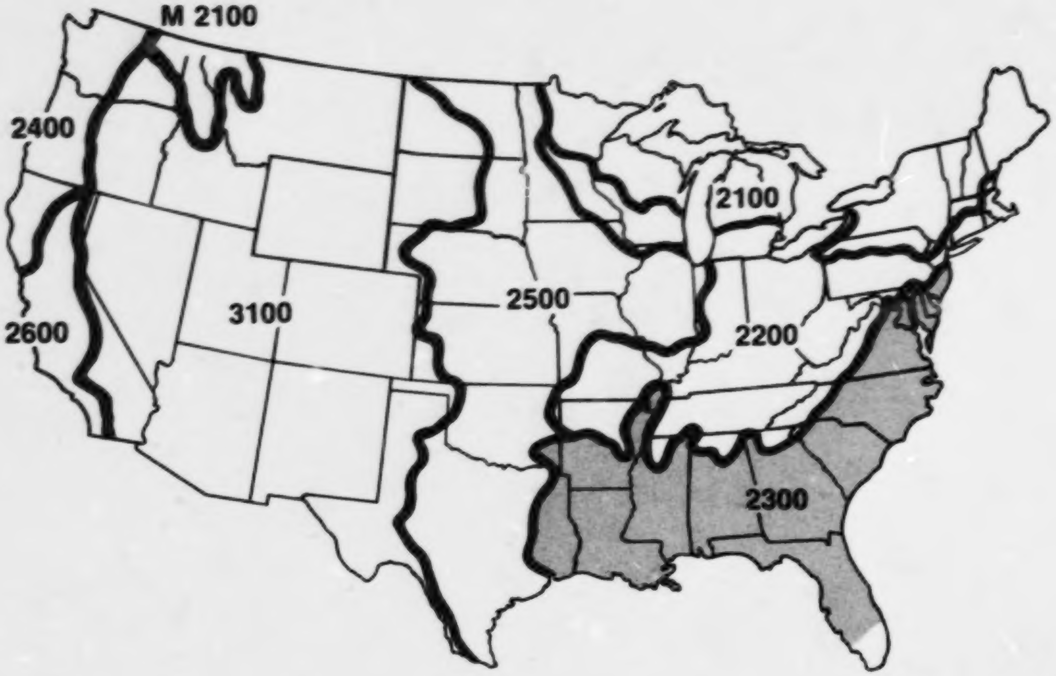

Figure 5. Ecoregion 2300 (After Bailey 1976).

HUMID SUBTROPICAL

This region occupies about 408,000 square miles, or 12.3 percent, of the total land mass in the United States. It is characterized largely by low relief (less than 300 feet), but some parts are gently rolling. In the lower coastal plains the streams are sluggish; in the upper coastal plains, they range from swift to turbulent. In some areas, there are many marshes and swamps.

This area is characterized as a temperate rainy climate with hot summers. The average temperature of the warmest month is over 71.6°F. Rainfall is ample, but distinctly greater during the summer; even the driest summer month receives more than 1.2 inches of rain. Thunderstorms are especially frequent in the summer.

Soils of the moister, warmer parts of the region are strongly leached red-yellow soils related to the Oxisols and Ultisols (Latosols) of the humid tropical and equatorial climates. Rich in iron and aluminum oxides, these soils are poor in many plant nutrients essential for successful agricultural production. Soils of the cooler parts of the region are similar to those found in Ecoregion 2200 (Alfisols, Podosols).

Vegetation of the outer coastal plain, is characterized by temperate pine, pine-hardwood, hardwood and wetland forests. There are also large areas of loblolly and slash pines and bald-cypress, but this vegetation represents forms in excessively dry or wet habitats. The climax vegetation is conifer-oak forest. There is a well developed strata of vegetation that in different places may include mosses, ferns, palms, shrubs and herbs. The inland area is characterized by summer green deciduous forest like that described in Ecoregion 2200.

TABLE 5. MAJOR SILVICULTURAL ACTIVITIES AND ACCESS PRACTICES IN ECOREGION 2300

SILVICULTURAL TYPE	HARVESTING ACTIVITIES			CULTURAL TREATMENTS			ACCESS	
	HARVESTING PRACTICES	LOGGING SYSTEMS	SLASH DISPOSAL	SITE PREPARATION	STOCKING CONTROL	OTHER	TEMPORARY ROADS	PERMANENT ROADS
Longleaf slash pine	Clearcutting is the primary regeneration cutting system with seed tree and shelterwood systems used also. Size of cutting blocks range from 10 to 100 acres on National Forests and up to 250 acres on industry-owned land. Commercial thinnings are made. Associate species are loblolly pine, pond pine and scrub oak.	Rubber-tired skidders dominate, although there is limited use of crawler tractors with steel tracks. Felling is done by chain saws, shears, and feller bunchers. A few harvesters are used that fell, delimb, top, and buck small trees into pulpwood bolts. Log storage on cutting areas is of short duration.	None	Artificial regeneration is done by machine or hand planting, and row or aerial seeding. Sites are prepared by machine clearing and piling in windrows, chopping, broadcast burning, bedding, discing, and chaining. For natural regeneration, chopping, discing, and broadcast burning are used.	A limited amount of precommercial thinning is done by machine. Release work is accomplished by hand tools such as chain saws, axes, and brush hooks and by herbicides using mist blowers, aerial application and tree injectors.	Insect control is done by harvesting and limited pesticide use. Diseases are handled by harvesting and prescribed burning. Fertilization is done by ground and aerial means.	Temporary roads may be constructed on any cross slope, but the vast majority are on gentle slopes of from 0 to 15 percent. Road density is too variable to establish an average. Lack of design and construction control allows the width to vary greatly. Widths may vary from 10 to 20 feet, with an average of about 15 feet. Turnouts are seldom constructed and any cut slopes are usually vertical. When both cross slopes and grades are flat, a temporary road is often only a cleared way thru the trees. On steeper grades, the surface is drained primarily with water bars and in places with drainage dips. Cross drainage structures are temporary. Temporary road surfaces are of native material. Normal road grades usually vary from 0 to 7 percent. Short pitches to 15 percent occur, but are rare. Vegetation is established on bare areas by application of grass seed and fertilizer. Temporary roads are returned to resource production when tributary timber has been removed. Depending on project conditions this work may include removing temporary drainage structures, outsloping and scarifying the driving surface, constructing additional water bars, and then seeding bare areas. Access points are physically blocked.	Permanent road densities throughout the ecoregion average about 2.5 miles per square mile. Roads may be constructed on slopes of from 0 to 35 percent with the vast majority built on slopes of from 2 to 15 percent. The typical permanent road is single lane with turnouts and has a 12-foot running surface. Normally surface water is removed by parallel ditches and culverts. Where slopes are steep, soils are stable and there is little or no groundwater, surface water may be removed by out-sloping and constructing drainage dips. Across flat, wet, unstable areas, roads are constructed on thru fills. Cross drainage is accomplished by use of permanent structures. Design speeds are usually 10 mph or less. Most roads are gravel surfaced to provide structural support for logging traffic. Usual road grades are between 2 and 7 percent. Short pitches may reach 10 percent. Cut slopes, fill slopes, and ditches are usually seeded, fertilized and mulched.
Loblolly short leaf pine	Clearcutting is the main regeneration cutting system with seed-tree system used also. Size of cutting blocks range from 10 to 100 acres on National Forests and private land and up to 250 acres on large industry-owned land. Comercial thinnings are made. Associate species are Virginia pine, sweetgum, oaks, hickories, and yellow poplar.	Rubber-tired skidders dominate, although the crawler tractor with steel tracks is used also. Felling is done with chain saws, shears, and feller-bunchers. Log storage on the cutting area is of short duration.	None	Artificial regeneration is done by machine or hand planting, and by row or broadcast seeding. Site preparation is by machine clearing and piling in windrows, chopping, broadcast burning, herbicide application by aerial means, mist blowers and tree injectors, and by hand tools such as chain saws and axes. For seed-tree areas, site preparation is by chopping, discing, broadcast burning, herbicide application by mist blower or tree injector, and by hand tools.	A limited amount of precommercial thinning is done by machine or hand tools. Release work is done by hand tools, and herbicide application by aerial means, mist blowers and tree injectors.	Insect control is done by harvesting and limited pesticide use. Diseases are handled by harvesting.		
Oak-hickory	Clearcutting is the main regeneration cutting system with limited use of shelterwood. The selection system is used on some small private ownerships. Size of cutting blocks range from individual trees to 50 acres. Commercial thinnings are made. Associate species are loblolly pine, shortleaf and Virginia pines, yellow-poplar, red maple, and sweetgum.	Rubber-tired skidders and crawler tractors with steel treads are used. Felling is by chain saws. Log storage on cutting areas is of short duration.	None	Site preparation for natural regeneration is by machine crushing, herbicide application by tree injector, and hand tools such as chain saws and axes. When planting is done, site preparation is by machine clearing and piling in windrows.	Precommercial thinning is done by herbicide application by tree injector and by chain saws, axes, and brush hooks. Release is by tree injector or chain saws.	None		
Oak-gum-cypress	The main regeneration cutting system is clearcutting, with the selection system used by some private landowners. Size of cutting blocks range from individual trees to 200 acres. Commercial thinnings are made. Associate species are slash and pond pines, yellow-poplar, and red maple.	Rubber-tired skidders and crawler tractors with steel tracks are used. A small amount of ground cable skidding is used. Felling is done by chain saws and feller-bunchers. Log storage on cutting areas is of short duration.	None	Site preparation for natural regeneration is by machine crushing, herbicide application by injector, and by hand tools such as chain saws and axes. Site preparation for planting of cottonwood is by machine clearing and piling in windrows, and by discing. Some drainage control is done.	A limited amount of precommercial thinning and release work is done through herbicide application by tree injectors, and by hand tools such as chain saws, axes, and brush hooks. Cottonwood plantations are disced for grass and weed control.	None		

SUMMARY OF HARVESTING ACTIVITIES AND CULTURAL TREATMENTS

Clearcutting is the primary regeneration cutting system. Seed tree and shelterwood are used to a lesser extent; there is very limited use of the selection system. Rubber-tired skidders are used extensively with some use of crawler tractors with steel tracks. Felling is done by chain saws, shears, and feller-bunchers. Log storage on the cutting area is of short duration. No slash disposal is done.

Artificial regeneration is by machine or hand planting and row or broadcast seeding. Site preparation and stocking control are accomplished by a wide variety of activities and methods because the terrain varies from flat to hilly and the treatments range from light to intensive. Insects are controlled by harvesting and limited use of pesticides; diseases by harvesting and prescribed burnings.

EROSION POTENTIAL CODE

☐ INDICATES GREATEST EROSION POTENTIAL

☐ INDICATES MODERATE EROSION POTENTIAL

☐ INDICATES LOW EROSION POTENTIAL

ECOREGION 2300: HUMID SUBTROPICAL

EROSION HAZARDS AND POTENTIALS

Flat slopes, structurally unstable, moderately erosive soils, and high moisture conditions characterize this ecoregion. Surface erosion is generally low over most of the area, increasing in the Piedmont where the ground steepens and isolated areas such as the loessal bluffs near the Mississippi River. Mass wasting is nil. Site preparation often contributes the greatest erosion potential on sites that are intensively managed. In other areas, access practices, notably temporary roads, may contribute to the largest erosion potential. Mechanized tree harvesting methods have the potential for disturbing sites and may present moderate erosion potential in some areas.

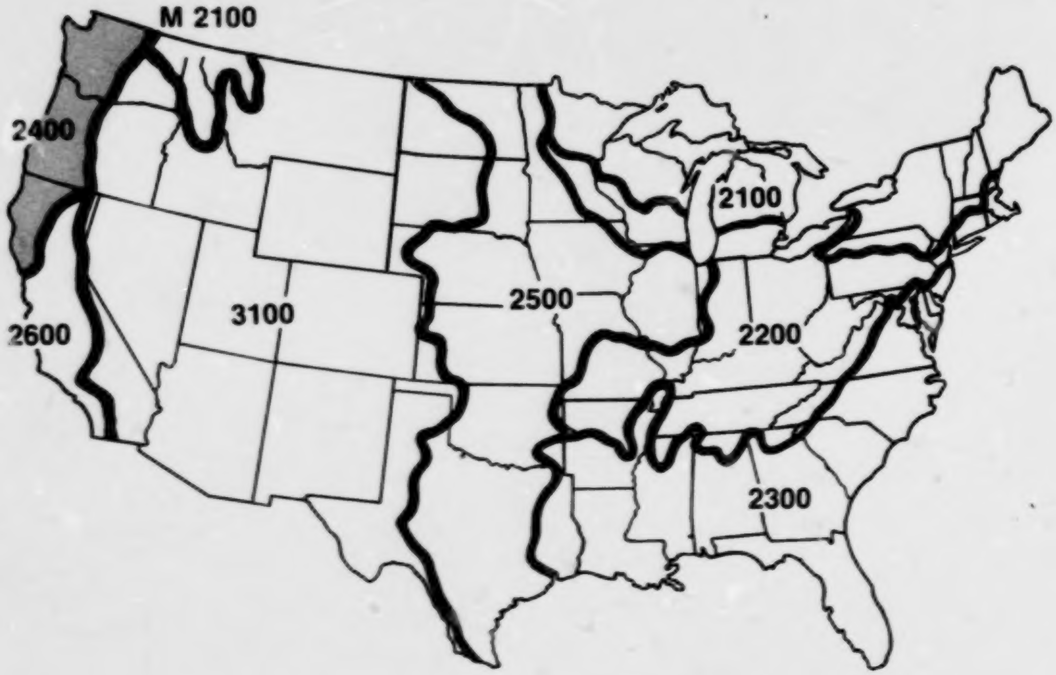

Figure 6. Ecoregion 2400 (After Bailey 1976).

HUMID MARITIME

This region occupies about 76,000 square miles, or 2.5 percent, of the total land mass in the United States. It consists of a series of steep, rugged mountains, but in places there is a narrow coastal plain. Mountains along the coast rise to 5,000 feet above sea level and have local relief of 1,000 to 3,000 feet. The interior Cascade Range consists of high mountains 8,000 to 9,000 feet in altitude, surmounted at intervals of 5 to 85 miles by volcanoes of much higher elevation. Much of the region has been glaciated, especially in the northern portion.

This maritime West Coast climate is characterized as rainy with warm summers. Average temperature of the warmest month is under 71.6°F, but at least four months average 50°F or more. Precipitation is considerable (30 to 150 inches or more) but is well distributed throughout the year, although there is a distinct reduction during summer months. Cooler air temperatures reduce evaporation and produce a very damp, humid climate with much cloud cover. The small annual temperature range makes for mild winters and relatively cool summers.

Soils of this climate are the Alfisols, Spodosols, and Inceptisols; they are of a strongly leached type and acid in nature. Bacterial activity is slow because of the cool temperature, and organic matter is not consumed readily, forming conifer surface deposits. Bases are removed because organic acids from decomposing vegetation react with soil compounds.

These dense conifer forests are primarily montane in character. Douglas-fir, western hemlock, western red cedar, and spruce grow on the coastal ranges of the Pacific northwest. Shrubs of many kinds are well developed in and around the forest.

The humid conifer forest changes in southwestern Oregon due to the fact that *amabilis* fir is replaced by redwood. In northwestern California, redwood is the characteristic tree of the fog belt. Associated with it are Douglas-fir and other conifers. These are perhaps the densest of all coniferous forests, with the world's tallest trees. In the higher mountains a well marked subalpine belt is present.

TABLE 6. MAJOR SILVICULTURAL ACTIVITIES AND ACCESS PRACTICES IN ECOREGION 2400

SILVICULTURAL TYPE	HARVESTING ACTIVITIES		CULTURAL TREATMENTS				ACCESS	
	HARVESTING PRACTICES	LOGGING SYSTEMS	SLASH DISPOSAL	SITE PREPARATION	STOCKING CONTROL	OTHER	TEMPORARY ROADS	PERMANENT ROADS
Western hemlock-Sitka spruce	Clearcutting patches of 20 to 100 acres is the predominant practice. Average clearcuts are about 40 acres. Clearcuts on private ownerships are often larger, up to 200 acres and often occur in progressive strips. Selection and seed tree cuts are rarely used. Shelterwood cuts are occasionally used when mistletoe infection is not a problem. Associated species are Douglas-fir, alder, western redcedar, Pacific silver fir, and redwood in the south.	All logging systems are used including balloon. Cable systems predominate and particularly the ground skid or high lead. Tractor skidders are generally limited to drier sites where soil compaction is not a problem, or to slopes under 30 percent on public lands and up to 45 percent on private lands. The largest and heaviest logging equipment operates in this type.	In clearcut areas, slash is broadcast burned with YUM yarding. In selection areas, where feasible concentrations are machine piled and burned. YUM yarding is common.	After logging and slash disposal, clearcuts are hand planted.	No precommercial thinning. Some hand chemical treatment for release of the conifers from brush competition.	Significant areas of industrial forest lands are aerially fertilized.	These roads are used primarily on flatter slopes in conjunction with tractor tree removal systems. Roads may be constructed on any cross slope but the majority are on relatively gentle slopes of 20 to 40 percent. Road density varies greatly. Widths vary from 10 to 20 feet, averaging about 18 feet. Turnouts are seldom constructed and cut slopes are usually vertical. The road surface is drained primarily by water bars and occasionally structures are temporary. Road surfaces are normally native materials. Occasionally the surface is spot graveled. Road grades are generally between 2 and 10 percent with occasional pitches to 20 percent. Bare soil is usually grass seeded. Temporary roads are commonly returned to resource production when tributary timber has been removed. Usual treatment is to remove drainage structures, scarify and outslope driving surface, construct additional water bars, and seed exposed surfaces with grass. Policy on public lands is beginning to de-emphasize the construction and use of temporary roads in favor of properly constructed and maintained permanent roads with lower densities.	Road densities vary from 2 to 6 miles per square mile depending on the tree removal system. Tractor skidding requires more, and long span cable systems require less mileage. Roads are constructed on side slopes from 0 to over 100 percent with the majority built on 30 to 55 percent slopes. The typical road is single lane with turnouts and has a 12-foot running surface. Parallel ditches and culverts drain the surface. Cross drainage is accomplished by permanent structures. Design speeds vary from 10 mph or less in steep areas to 20 mph in less rugged terrain. Variations include outsloped surfaces with drainage dips on flatter cross slopes and more stable soil conditions, and insloped surfaces with either drainage dips or culverts on steeper cross slopes. On cross slopes greater than 55 to 60 percent the entire road surface is benched into the hillside, excess material being end hauled to an appropriate disposal site. The majority are gravel surfaced, the thickness varying with structural requirements. Asphalt surfacing is sometimes used on steep road grades across unstable soils. Road grades are usually between 7 and 10 percent. Maximum grades are 20 percent, usually to avoid steep, unstable slopes. Vegetation is established on cut-and-fill slopes by hydroseeding with a mixture of seed, fertilizer, and mulch. Most permanent timber roads on public lands remain open to public use. The trend is to close minor roads between periods of timber or fire activity.
Douglas-fir	Principal harvest is clear cutting in patches of 5-100 acres with a 40-acre average. Private clearcuts are usually more extensive, and in hardwood conversions may be several hundred acres. Acres with dry slopes or frost problems may be given shelterwood treatment. Seed tree or selection are seldom used. Associated species are western hemlock, western redcedar, grand fir, Pacific silver fir, noble fir, mountain hemlock and western white pine.	All logging systems are used except balloons. Cable systems, ground skidding and tractors predominate. Tractors or skidders are commonly used on slopes up to 40 percent — occasionally to 50 percent — except where soil conditions are critical. Very large equipment is common.	Clearcuts are broadcast burned and YUM yarded. Slash concentrations in selection and shelterwood cuts are commonly machine piled and burned where feasible. Infrequently YUM yarding is used as is spot burning or lop and scatter.	Clearcuts are hand planted after burning. The majority of selection or shelterwood cuts are hand planted after slash disposal.	Substantial acres precommercially thinned. Little if any associated slash disposal. Large acreages aerially sprayed with herbicides for release from brush competition.	See western hemlock-Sitka spruce type		
Mixed conifer	Complexity of the type requires that both even-aged and uneven-aged methods be used. No single system is applicable throughout the type. On dry sites where seasonal frosts are common, selection or shelterwood is used. Many sites are harvested by clearcuts of 5-100 acres, larger on private lands. Most clearcuts on public lands averaged 25 acres. Predominant species are ponderosa pine, Douglas-fir and white pine.	Tractor and/or skidders are the predominate tree removal technique on slopes to 40 percent, occasionally to 50 percent. All cable systems are commonly used on steep slopes. Type of cable system is dependent on soil stability and harvest system. Helicopters are frequently used.	See western hemlock-Sitka spruce type	See Douglas-fir type	See Douglas-fir type	See western hemlock-Sitka spruce type		
True fir-mountain hemlock	Chief harvesting practice is clearcutting in patches of 20-30 acres or strips to avoid adverse climatic conditions. Some stands are managed using shelterwood or selection when stand composition dictates. Associated species are noble fir, Pacific silver fir, red fir, Douglas-fir, white fir, western white pine, subalpine fir and Englemann spruce.	See mixed conifer type	See western hemlock-Sitka spruce type	See Douglas-fir type	None	None		
Redwood	Clearcuts up to 40 acres predominate. Limited amounts of shelterwood and seed-tree cutting are undertaken. Associated species are Douglas-fir, Sitka spruce, grand fir and western hemlock.	See western hemlock-Sitka spruce type	See western hemlock-Sitka spruce type	Occasional fill-in planting needed	See western hemlock-Sitka spruce type	None		
Alder-conifer	Clearcut blocks of 5-50 acres predominate. Associated species are Douglas-fir, hemlock, spruce.	Tractors are used on drier sites to about 30 percent. Ground skidding cable systems are used on steeper dry sites; partial suspension cable systems used on steep, wet areas.	Broadcast burn except where machine piling and burning is feasible.	Sites hand planted after burning.	Young unmerchantable stands often aerially sprayed for release.	None		
Ponderosa pine	Common harvesting practices are selection and shelterwood. Some clearcutting is undertaken in 2-20 acre blocks. Ponderosa pine often occurs in pure stands. Associated species are lodgepole pine, white fir, Douglas-fir and incense cedar.	See mixed conifer type	See western hemlock-Sitka spruce type	Clearcuts and shelterwood cuts are machine or hand planted. Selection cuts occasionally require fill-in planting.	Large areas precommercially thinned with varying slash disposal, including machine pile, hand pile and machine crush. Occasional broadcast or spot burning. Some aerial spraying for release.	See western hemlock-Sitka spruce type		

SUMMARY OF HARVESTING ACTIVITIES AND CULTURAL TREATMENTS

Clearcutting is the most prevalent form of silvicultural management although all methods of even-aged and uneven-aged management are applied. A wide variety of tree removal systems are utilized including rubber tire and steel track skidders, jammer, drum and skyline cable systems, balloons, and helicopters. Slash disposal is an important function to improve regeneration and reduce fire hazards. Site preparation often includes the use of mechanical equipment. Regeneration is predominately artifical, often by broadcast seeding, machine or hand planting. Thinnings are used in more commercially valuable types. Release is often accomplished by aerial application of chemicals. A common road-building practice is to avoid construction on steep, unstable slopes in favor of ridge-top roads.

EROSION POTENTIAL CODE

☐ INDICATES GREATEST EROSION POTENTIAL
☐ INDICATES MODERATE EROSION POTENTIAL
☐ INDICATES LOW EROSION POTENTIAL

ECOREGION 2400: HUMID MARITIME

EROSION HAZARDS AND POTENTIALS

Steep slopes, unstable soils and high moisture conditions contribute to erosion and mass failure problems and give roading activities the highest erosion potential. Temporary roads have the greatest potential. Construction of roads, location and density, and maintenance are the most hazardous activities. Tree harvest and removal are of secondary erosion potential. Skidding and moving logs to landings create the most problems. Ground skidding has the largest impact whereas full suspension has the least. Problems from slash disposal arise largely from machine piling and burning. Site preparation often exposes soil to erosive energy. Timing and intensity of thinnings and release involve the greatest impacts from intermediate cultural treatments.

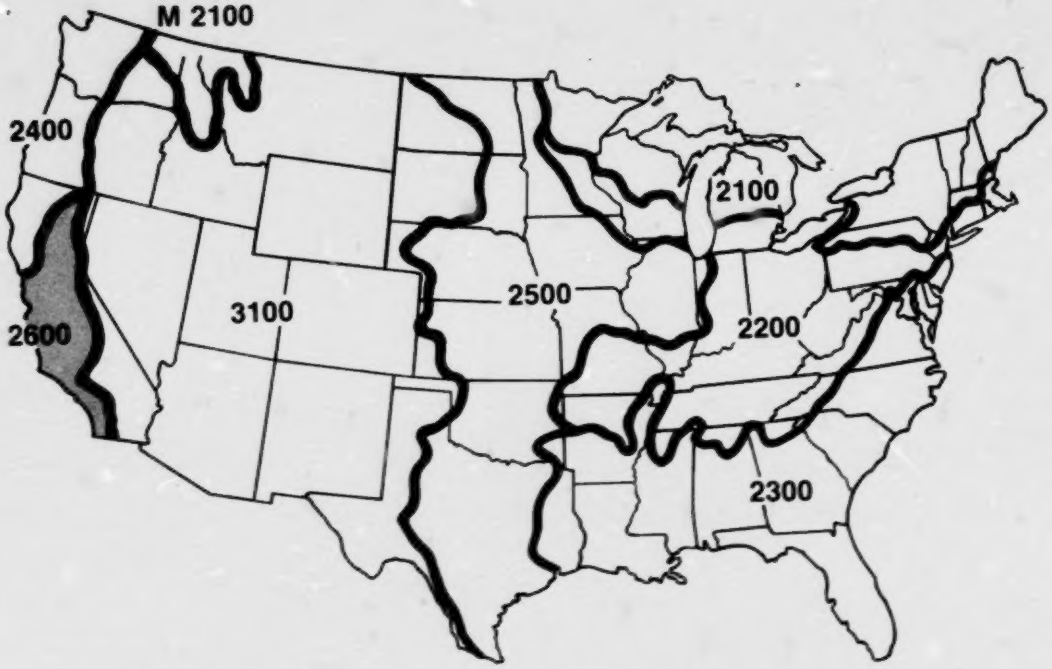

Figure 7. Ecoregion 2600 (After Bailey 1976).

MEDITERRANEAN

The topography of this region is greatly varied, for it includes the Coast Range along the Pacific Ocean, the plains of the central valley of California, and the glaciated Sierra Nevada range. Elevation ranges from sea level to over 14,000 feet. This region occupies about 86,300 square miles, or 2.7 percent, of the total land mass of the United States.

This area is subject to alternate wet and dry seasons because it is located in the transition zone between the dry, West Coast desert and the wet, West Coast climate. It is characterized as a temperate, rainy climate with dry, hot summers and summer droughts.

Soils of this climate are not readily subject to classification. Reddish chestnut (Alfisols, Mollisols) and reddish brown soils (Aridisols), typical of the semiarid climate, are present.

The presence of a wet winter and a dry summer is unique among climate types and results in distinctive natural vegetation of hardleafed evergreen trees and shrubs — sclerophyll forest. Various forms of sclerophyll woodland and shrub are also typical. The vegetation must be able to withstand severe summer drought. Ecologic zones are exceptionally well marked. Grassland covers the floor of the larger valleys; a zone of oaks and chaparral occupies the hills and lower mountains; the montane and subalpine belts together include conifer forests of the higher mountains; and the alpine zone is the treeless area above timberline.

TABLE 7. MAJOR SILVICULTURAL ACTIVITIES AND ACCESS PRACTICES IN ECOREGION 2600

SILVICULTURAL TYPE[1]	HARVESTING ACTIVITIES			CULTURAL TREATMENTS			ACCESS	
	HARVESTING PRACTICES	LOGGING SYSTEMS	SLASH DISPOSAL	SITE PREPARATION	STOCKING CONTROL	OTHER	TEMPORARY ROADS	PERMANENT ROADS
Ponderosa-Jeffrey pine	Selection is the most frequent practice; shelterwood and clearcut are used less frequently. Clearcuts are usually 2 to 20 acres, occasionally to 50 acres. This type usually consists of pure stands, but it may contain incense cedar or Coulter pine.	All three harvest practices are accomplished with tractors and/or skidders, except in the northern California area where cable-ground skid, partial suspension, full suspension and helicopter may be used for all practices. Tractors and/or skidders are used on slopes to about 40 percent on public land; up to 60 percent on others.	In clearcuts, swamper burn is common, with broadcast burn and some YUM yarding also being used. In selection cuts, broadcast burn, lop and scatter, machine pile and burn are all typical. Machine pile and burn is used in tractor-skidder shelterwood cuts; lop and scatter and swamper burn in cable areas.	Following slash disposal, clearcuts are machine or hand planted. Hand interplanting is common in selection cutting to enhance stocking. In shelterwood, scarification is done through logging, slash disposal or other means and normally hand or machine planted.	Significant precommercial thinning follows selection cutting. This is done by chain saw. Slash is disposed of by hand piling, occasionally by chipping. Release is accomplished through hand chemical application. This kind of stocking control also applies frequently in shelterwood cuts.	Extensive acreages of old burns are cleared of brush, and mineral soil exposed for hand or machine planting. Extensive acreages of brush are chemically treated by air or hand methods for release of conifers. Extensive acreages of private land are aerially fertilized.	Temporary roads are used primarily on the flatter slopes in conjunction with tractor tree removal systems. Temporary roads may be constructed on any cross slope, but the vast majority are on relatively gentle cross slopes of 15 to 35 percent. Road density is too variable to establish an average. Lack of design and construction control allow the width to vary greatly from 10 to 20 feet with an average of about 18 feet. Turnouts are seldom constructed and cut slopes are usually vertical. The road surface is drained primarily with water bars and occasionally by drainage dips. Cross-drainage structures are temporary. Temporary road surfaces are of native material. Road grades are normally between 2 and 10 percent and seldom exceed 15 percent. Pitches to 20 percent are rare. There is very little attempt made to establish vegetative cover on bare areas. Temporary roads are returned to resource production when tributary timber has been removed. Usual treatment is to remove temporary drainage structures, outslope the driving surface and construct additional water bars. Access points are physically blocked. Many temporary roads were built in the past, some being returned to production and some not. The present practice is to build properly located, designed, and constructed permanent roads whenever future need is anticipated, thereby substantially reducing or eliminating temporary road density.	Permanent road densities vary from 2 to 6 miles per square mile depending on both the tree removal system and the ground slope; the higher density is a result of logging by tractor skidding on moderately steep slopes. Density decreases on steeper slopes where cable removal systems are used and on flatter slopes where longer skidding distances are practical. Roads are constructed on side slopes of 0 to 65 percent; the majority of the mileage is on slopes between 15 and 35 percent. The typical permanent road is single lane with turnouts, and it has a 12- to 14-foot running surface. Parallel ditches and culverts drain the surface in the flatter country, while outsloped surfaces with drainage dips are a common practice as the terrain steepens. Cross drainage is accomplished by use of permanent structures. Design speeds vary from 10 mph or less in steep areas, to 20 mph and occasionally to 30 mph in easier terrain. No surface drainage features are required in the pure pumice soil type. Where cross slopes greater than 55 to 60 percent are encountered, the entire road surface is benched into the hillside and excess material is end hauled to an appropriate disposal site. Gravel surfacing is the exception rather than the rule and is used only where needed for structural support of wheel loads. Usually permanent road grades are between 2 and 10 percent. Grades seldom exceed 15 percent, but in places will pitch to 20 percent. These steep grades are usually used to avoid location on steep, unstable slopes. The relatively dry climate and mineral soils in this region make the establishment of vegetative cover on bare soil difficult at best. When it is thought that cover can be established, grass seed and sometimes fertilizer are applied to cut and fill slopes. No attempt is made to establish vegetative cover in areas where results are expected to be nil. There is a trend towards closing permanent timber roads to public use. It is not uncommon to prohibit traffic on an otherwise open road in the spring when structural stability is lost due to melting frost. Where it is necessary to harvest timber on slopes over 30 to 40 percent, trees are removed from the site by one of the cable systems.
Douglas-fir	See mixed conifer type. This type is found in only limited areas north of Redding. Associate species are sugar pine and white fir.	See mixed conifer type for logging systems in northern California.	See mixed conifer type.	Depending on terrain, clearcuts are machine piled and burned or broadcast burned and hand planted.	Occasional reproduction may remain in clearcuts and may be thinned.	None		
Mixed conifer	Clearcutting, shelterwood and selection are all common practices. Also some seed tree cutting occurs in the southern Sierra Mountains. Clearcutting ranges from 2-200 acres, with the average about 25 acres. Predominately Ponderosa pine, with Douglas-fir, Jeffrey pine, Coulter pine, sugar pine, lodgepole pine, white fir, red fir, incense cedar, and western white pine.	Practices in southern Oregon are accomplished with tractor-skidder only. This is also the case in the southern Sierra Nevadas except that a cable-partial suspension system is used on slopes over 35 percent. In northern California tractor skidder, cable-partial suspension and helicopter are used in clearcuts, shelterwood, and selection. Also cable-ground skid and cable-full suspension are used in clearcuts.	On tractor shows, broadcast burn or machine pile and burn is used. On aerial shows combinations of swamper burn, lop and scatter, and YUM yarding are used. Hand piling is used rarely.	See ponderosa pine type.	See ponderosa pine type.	See ponderosa pine type.		
Lodgepole pine	Harvest of this silvicultural type is limited to northern California and southern Oregon. Practices are chiefly clearcutting in blocks of 20-200 acres, with some shelterwood and selection.	Logging is done by crawler tractor or rubber-tired skidder used interchangeably. Lodgepole is rarely found on the steeper slopes. In southern Oregon, selection and shelterwood cuts are logged with tractors or skidders. Use of the feller buncher is becoming fairly common.	Tractor pile and burn is the usual method in clearcuts; occasionally broadcast burn. Shelterwood slash is machine piled and burned, except on very hot, dry sites where chipping is used. Selection area slash is machine piled and burned, occasionally broadcast burned.	Clearcuts are machine planted after slash disposal. In Oregon natural regeneration is allowed to take place. In California shelterwood areas are hand planted after slash disposal.	In some selection areas precommercial thinning with a chain saw is followed by hand or machine piling and burning of the slash.	None		
True fir	Clearcutting in blocks of 5-100 acres is the predominant practice. Limited shelterwood and selection cutting may also occur. Predominately red fir, with Jeffrey pine, western white pine, lodgepole pine, white fir, and mountain hemlock.	All practices are limited to tractor or skidder logging. Helicopters are rarely used in selection cuts.	Common disposal for all practices is machine pile and burn with YUM yarding.	Clearcuts are hand planted after slash disposal. Shelterwood areas are scarified and hand or machine planted.	There is occasional precommercial thinning in shelterwood or selection cuts. No slash disposal.	None		
Black oak	Selection cutting is practiced on both private and public lands.	This silvicultural type is found only on the lower, flatter slopes and is tractor or skidder logged.	Machine pile and burn, occasionally broadcast burn are the common practices.	These sites usually support young oak; existing conifers are encouraged.	Stands are thinned with chain saw and the slash is piled and burned. Release is accomplished through hand chemical application.	None		

SUMMARY OF HARVESTING ACTIVITIES AND CULTURAL TREATMENTS

The predominating harvest practice is clearcutting in blocks of from 2-25 acres, with larger cuts also common. Selection and shelterwood are also practiced. The logging system is primarily by crawler tractor or rubber tired skidder used interchangeably; on slopes of over 35 to 40 percent other practices like cable-ground skid, partial or full suspension, and helicopter may be used. Slash disposal methods are related to harvesting practice, although it can be generalized that machine pile and burn and broadcast burn are the most frequently used methods. Hand piling is used rarely. Following disposal of slash the site is most frequently prepared by hand or machine planting; shelterwood areas are first scarified through the logging practice, then hand or machine planted.

Precommercial thinning is accomplished by chain saw, with the slash piled and burned. On the ponderosa or Jeffrey pine type release is done through hand chemical means. practices are applied which also expose the mineral soil, treat the brush, or fertilize.

EROSION POTENTIAL CODE

☐ INDICATES GREATEST EROSION POTENTIAL

☐ INDICATES MODERATE EROSION POTENTIAL

☐ INDICATES LOW EROSION POTENTIAL

ECOREGION 2600: MEDITERRANEAN

EROSION HAZARDS AND POTENTIALS

Moderate slopes, fairly stable soils, and moderate to low moisture conditions are characteristic of this ecoregion. Surface erosion potential and hazard are high in the steep, dry areas of the ecoregion and low in the flat, wet conditions. Mass movements may occur locally but are not a major problem region-wide. Design, location and construction of roads, most notably temporary roads, are a major erosion concern, although the system is largely design dictated by the logging system. Moderate erosion potentials arise from harvesting activities, including skidding and slash disposal. Site preparation and thinnings represent the cultural treatments that contribute to erosion potentials although overall the problems associated with cultural treatments are relatively low.

[1] For redwood silvicultural type, see Ecoregion 2400: Humid Maritime.

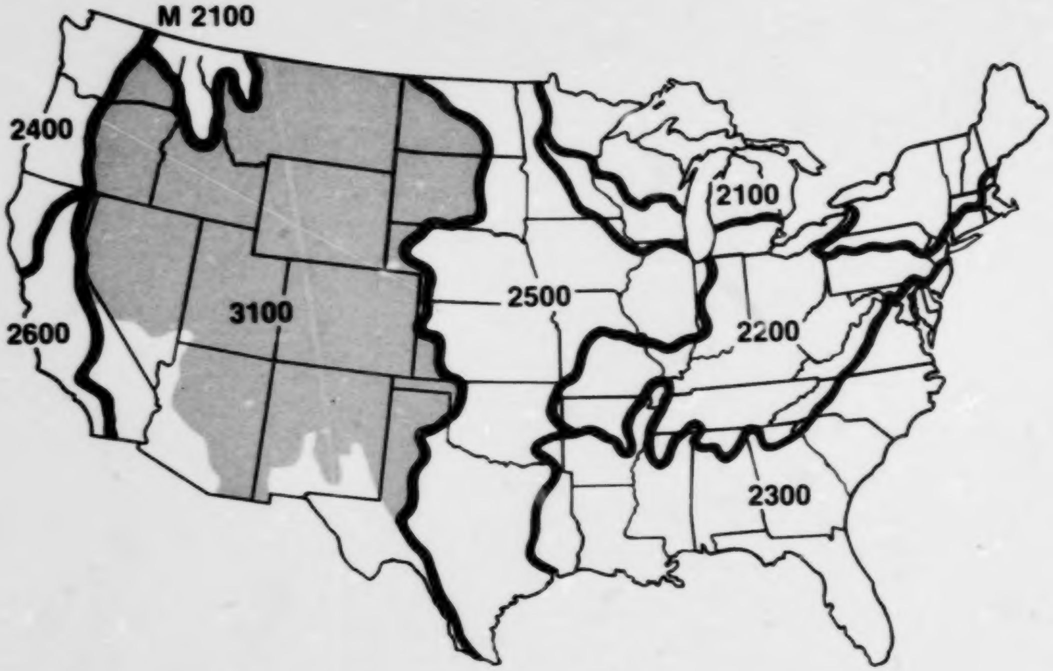

Figure 8. Ecoregion 3100 (After Bailey 1976).

SEMIARID STEPPE

This ecoregion occupies about 911,200 square miles, or 27.9 percent, of the total land mass in the United States. It is characterized by flat and rolling plains, tablelands of moderate to considerable relief, high elevation plateaus, interior basins, high rugged, glaciated mountains rising steeply from semiarid plains, intermontane depression having floors less than 6,000 feet in altitude, and volcanic mountains.

This region is associated with a semiarid continental climate regime in which, despite a summer rainfall maximum, evaporation exceeds precipitation on the average. The steppe is a transitional belt surrounding the desert and separating it from humid climates beyond. Winters are cold and dry; summers warm to hot. In mountainous areas, precipitation in winter is greater than in the plains areas.

Soils of this region are dominantly Mollisols, Aridisols and Alfisols, but timbered areas have many Inceptisols (Brown Forest, Gray-Brown Podzolic, Chernozem). The dominant soil process in this area is calcification, with salinization on the poorly drained soils. Humus content is relatively sparce wherever vegetation is sparse. Soils often contain an excess of precipitated calcium carbonate and are very rich in bases.

There are all gradations of vegetation into both semidesert and woodland varieties. In the plains areas are many species of short, bunched, prairie grasses (including alkali-tolerant ones), scattered xerophtic shrubs (sagebrush, for example) and low trees. Ground coverage may be small and much bare soil exposed. Mountainous areas are characterized as alpine tundra; trees absent. In the subalpine area, Englemann spruce and subalpine fir predominate, with aspen and lodgepole pine. In the montane areas are ponderosa pine and Douglas-fir.

TABLE 8. MAJOR SILVICULTURAL ACTIVITIES AND ACCESS PRACTICES IN ECOREGION 3100

SILVICULTURAL TYPE	HARVESTING ACTIVITIES			CULTURAL TREATMENTS			ACCESS	
	HARVESTING PRACTICES	LOGGING SYSTEMS	SLASH DISPOSAL	SITE PREPARATION	STOCKING CONTROL	OTHER	TEMPORARY ROADS	PERMANENT ROADS
Ponderosa pine	In the Rocky Mountains, the only harvesting practices are shelterwood and selection cutting. In addition, in central Idaho where Douglas-fir may be a major component, clearcutting in blocks of 5-20 acres may be used. Ponderosa pine most often occurs in pure stands. Associate species may include Douglas-fir.	Crawler tractors and rubber tired skidders, used interchangeably, are by far the most common means of logging. Horses are used where more sophisticated systems are not available; short span ground-skid and partial suspension cable systems and helicopters are sometimes used. Tractors or skidders are limited to about 40 percent slopes. In the Black Hills, logging is often done with feller-buncher skidder or skidder/harvester combinations.	Lop and scatter is the common technique for all selection cutting. In shelterwood and clearcut areas, machine piling and burning of concentrations is used where topography permits. YUM yarding is rarely used.	Shelterwood cuts are designed for scarification, followed by hand planting or natural regeneration. No regeneration is planned following selection cuts. Clearcuts are hand planted.	Following shelterwood cutting, substantial stands of residual are precommercially thinned with chain saws, and the slash is piled and burned. Only minor areas are thinned after selection. Slash is not treated.	None	Temporary roads are used in conjunction with the tractor tree removal system. Temporary roads may be constructed on any cross slope but the majority are on relatively gentle slopes of 0 to 35 percent. Road density is too variable to establish an average. Lack of design and construction control allows the width to vary greatly from 10 to 20 feet, with the average of about 18 feet. Turnouts are seldom constructed and cut slopes are usually vertical. The surface is drained primarily with water bars and in places with drainage dips. Cross drainage structures are temporary. Temporary road surfaces are of native material. Normal road grades vary from 0 to 10 percent with some pitches as steep as 20 percent. Vegetation is established on bare areas by application of grass seed, occasionally with fertilizer. Temporary roads are returned to resource production when tributary timber has been removed. Usual treatment is to remove temporary drainage structures, outslope and scarify the driving surface, construct additional water bars, and seed the bare areas. Access points are physically blocked. Many temporary roads were built in the past, some being closed and some not. Present practice is to build properly located, designed and constructed permanent roads whenever future need is anticipated, thereby substantially reducing or eliminating temporary road density.	Permanent road densities vary from 2 to 7 miles per square mile. Tractor skidding on very flat slopes and short span cable systems on steeper slopes require the least mileage. Roads may be constructed on slopes from 0 to over 100 percent with the majority on slopes of 20 to 45 percent. The typical permanent road is single lane, with turnouts, and it has a 10-to 14-foot running surface. In areas where slopes are moderate to steep with little or no ground water, and the soils stable, surface water is removed by outsloping and constructing drainage dips; otherwise, parallel ditches and culverts are used to remove surface water. Occasionally surfaces are insloped wherever side slopes and/or grades are steep. Cross drainage is accomplished by use of permanent structures. Design speeds vary from 10 mph or less in steep areas to 20 mph in less rugged terrain. Gravel surfacing is applied whenever it is needed for structural support or where native material is too rocky and rough for log hauling. Usually, permanent road grades are between 2 and 10 percent; the steeper the terrain the steeper the usual grade. Short pitches to 20 percent are occasionally encountered. Cut-and-fill slopes and, quite often, ditches are hydroseeded with fertilizer and mulch whenever soil and moisture conditions are conducive to establishment of grass cover. Over much of the ecoregion, conditions are too dry or soils too sterile for establishment of grass cover. Permanent timber roads may be either left open, or closed to public use depending on local conditions. Tree removal is primarily by tractor skidding. Short span cable systems are common on the steeper slopes in central Idaho and to a very limited extent throughout the remainder of the ecoregion.
Douglas-fir	Harvesting in order of occurrence is clearcutting, selection, shelterwood, and, infrequently, seed tree. Associate species are ponderosa pine, lodgepole pine, Englemann spruce, aspen, white fir, and corkbark fir.	See ponderosa pine type	In clearcuts, slash is broadcast burned in cable areas, machine piled and burned in tractor/skidder areas. All selection and shelterwood areas are lopped and scattered. Seed tree areas are machine piled and burned.	Clearcut and shelterwood areas are hand planted after slash disposal.	Very little thinning activity in this type.	None		
Englemann spruce	Harvesting is predominantly clearcutting in blocks of 2-20 acres, occasionally to 40 acres. Selection and shelterwood are also used. Associate species are subalpine fir, Douglas-fir, lodgepole pine, blue spruce, and corkbark fir.	Tractors or skidders are used for all practices on slopes to 35 percent. There is limited use of cable-ground skid and partial suspension systems in clearcuts over about 40 percent.	No one technique dominates in any harvest practice - may be one or a combination of broadcast burn, machine pile and burn, YUM yarding, and lop and scatter.	Clearcut and shelterwood areas are scarified through logging, slash disposal, or supplemental means and generally are hand planted.	Virtually no precommercial thinning or release in this type.	None		
Aspen	The predominant practice is clearcutting, only occasionally by selection cutting. Clearcuts range from 2-20 acres.	Virtually all logging is with the crawler tractor or rubber-tied skidder. Farm tractors are used infrequently on private lands.	Slash disposal is by lop and scatter. Rarely by other means.	Natural regeneration occurs without special effort.	The infrequent precommercial thinning is done with chain saws, and the slash is lopped and scattered.	None		
Lodgepole pine	The chief practice is clearcutting in blocks from 5-50 acres, with the average being 20 acres. Some selection cutting is done in younger stands. Lodgepole pine occurs in pure stands.	Most logging is done with the tractor or skidder. Also, significant amounts of horse logging and occasional cable-ground skidding takes place on the steeper slopes.	Broadcast burn or machine pile and burn are the most common methods in clearcuts. Lop and scatter is practiced in selection cut areas.	Necessary site scarification is accomplished thru logging and slash disposal. Those areas not seeded-in naturally are hand planted.	Substantial acreages are precommercially thinned, and where risk is high slash is hand or machine piled and burned.	None		
Mixed conifers	Harvest practices are shelterwood, selection and occasionally seed tree. Limited to Arizona and New Mexico. Associate species are ponderosa pine, Douglas-fir, white fir, blue spruce, subalpine fir, and aspen.	Crawler tractor and rubber-tired skidders are used interchangeabley for all practices on slopes up to 40 percent.	Shelterwood and selection cut slash is disposed of by machine piling and burning. Some YUM yarding and lop and scatter is practiced. Seed tree slash is disposed of by lop and scatter.	Shelterwood and seed-tree areas are scarified and hand planted.	Significant precommercial thinning is done with chain saws. Slash is hand or machine piled and burned.	None		
White spruce	Harvesting is by selection only. This type is limited to the Black Hills. Associate species are ponderosa pine, Douglas-fir and aspen.	Logging is done by tractor or skidder.	Slash disposal is by lop and scatter.	None necessary	None	None		

SUMMARY OF HARVESTING ACTIVITIES AND CULTURAL TREATMENTS

Clearcutting in an average block of from 2-20 acres is the most prevalent form of harvesting, with selection cutting second; other methods are less frequent. On slopes of up to 40 percent logging is accomplished by crawler tractor and/or rubber-tired skidder; cable-ground skids are used on the steeper slopes. Disposal of slash is tied to both the method of harvesting and the logging system; lop and scatter and machine piling and burning are the most common methods, although other techniques are also used. On some silvicultural types natural regeneration occurs without special effort; where the site must be prepared, scarification is commonly accomplished through logging method and/or slash disposal. It is then followed by hand planting.

Precommercial thinning is accomplished on most silvicultural types with chain saws, and the slash is then piled and burned. Some types require virtually no precommercial thinning.

EROSION POTENTIAL CODE

☐ INDICATES GREATEST EROSION POTENTIAL

☐ INDICATES MODERATE EROSION POTENTIAL

☐ INDICATES LOW EROSION POTENTIAL

ECOREGION 3100: SEMIARID STEPPE

EROSION HAZARDS AND POTENTIALS

Slopes varying from flat to vertical, erosive soils, local areas subject to mass movement, and low moisture conditions characterize this ecoregion. Surface and mass erosion hazard vary from nil to very high, increasing with the slope of the ground and precipitation intensity and distribution. The wide diversity of geographic conditions, which accounts for much variation in precipitation patterns, contribute to the greatest potentials; location, design and construction of roads are the major influencing activities. Temporary roads create more erosion problems than permanent roads. Logging systems influence access system design, however. Site preparation and thinnings are cultural treatments which contribute to erosion potentials, but are relatively low.

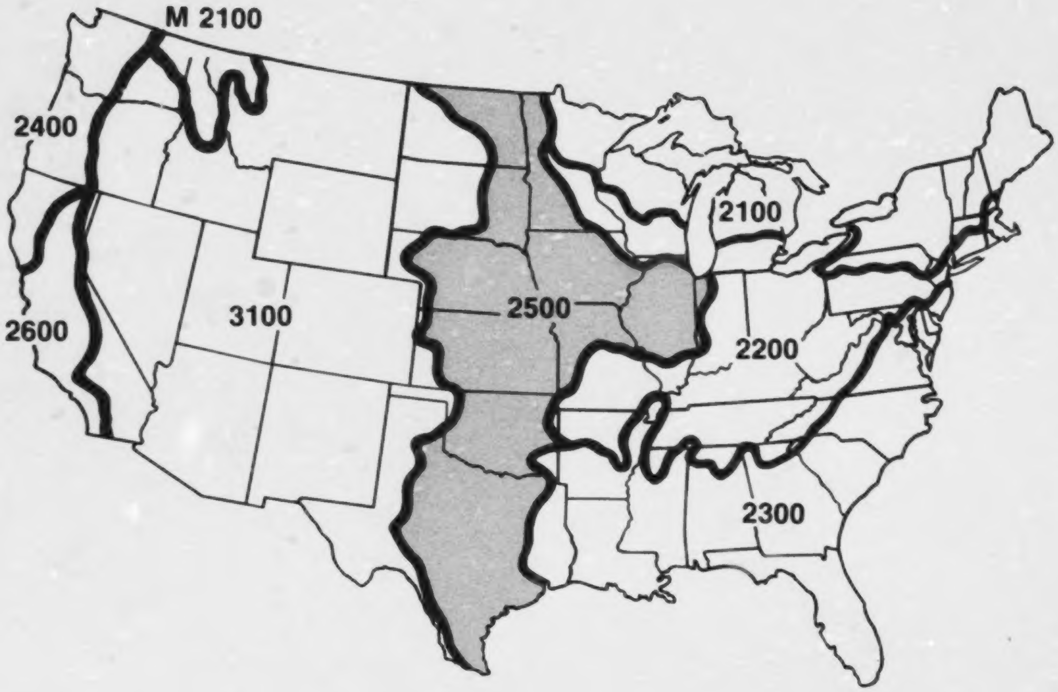

Figure 9. Ecoregion 2500 (After Bailey 1976).

PRAIRIE

The North American Prairie consists of smooth to undulating plains with low relief (less than 300 feet), but some areas are hilly. Elevation ranges from sea level to 2,000 feet. The northern part has been glaciated. The ecoregion occupies about 511,000 square miles, or about 15.5 percent, of the total land mass in the United States.

This area lies on the more arid western side of the humid continental climates, and with decreasing latitude extends over into subtropical climates. The temperature characteristic of the climate corresponds to those of adjacent humid climates. However, in summer air and soil temperatures are high, so that on uplands, soil moisture is not adequate for tree growth, and deeper water sources are beyond the reach of tree roots.

Soils of this region are Mollisols and Alfisols (Chernozem, Chestnut and Brown soils). The soil process associated with prairie vegetation is calcification and results in soil profiles characterized by thick, dark-brown *A* and *B* horizons. Grass roots penetrate these soils deeply. Bases brought to the surface by plant growth are released upon the surface and restored to the soil, thus perpetuating soil fertility.

The natural vegetation of the prairie consists of tall grasses comprising the dominant herbs, and subdominant forbs (broad-leaved herbs). Trees and shrubs are almost totally absent but may occur in valley or other topographic depressions as forest or woodland patches.[2]

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[2] This ecoregion has not been characterized by silvicultural type, and therefore it has no ecoregion table that accompanies it. For a discussion of silvicultural types that do occur in this ecoregion, see the appropriate ecoregion tables.

CHAPTER 3

BASIC CONCEPTS OF COST-EFFECTIVENESS ANALYSIS

The objective of this chapter is to outline the basic concepts of cost-effectiveness analysis. These concepts form the general method for conducting an analysis. Individual applications of the method may require more detailed and rigorous procedures to fit specific characteristics of any single analysis.

Cost-effectiveness analysis is an economic model that applies to specific types of problems and can be used in decision-making. The proper context for applying it, and the inputs (i.e., measures of effectiveness and costs), are the essentials for successful application of the model.

The use of cost-effectiveness analysis assumes that there are alternative ways of reaching an objective, each alternative requiring certain resources and producing certain results (ARINC Research Corporation 1970). A key characteristic of cost-effectiveness analysis is that the objective can be reached by more than one single system or program. Thus, the purpose of the analysis is to determine the "best" system or program for meeting the objective.

An example will illustrate these ideas more fully. Suppose a forest manager is charged with developing a program to reduce non-point source pollution from erosion caused by silvicultural activities. The objective is erosion reduction; and the manager has several options for meeting it, including the choice of harvest system, equipment employed, intensity of management, etc. Cost-effectiveness analysis will provide him a model to deal with evaluation of those options contributing to meeting the goal.

Specific conditions for using cost-effectiveness analysis need to be discussed.

First, this kind of analysis is an attempt to minimize dollar costs subject to a performance requirement (which may or may not be measurable in dollar terms) or, conversely, to maximize some measure of output subject to a budget constraint (Washington Operations Research Council 1967). A conclusion that could be drawn is that cost-effectiveness analysis can result in economic suboptimization; that is, because the analysis deals only with cost and not the relationship between cost and revenues, there is no basis for evaluating the efficiency of the solution.

In the case of non-point source erosion controls, cost-effectiveness analysis can be used to examine alternative sets of controls to determine a "least-cost" solution subject to a performance standard. The emphasis is placed upon the relationship between the value of resource inputs (outlays or opportunity costs) and the indicators of program outputs (effectiveness). The benefit or revenue ledger plays a subordinate role, especially with regard to external benefits or alternate operating scales, because these benefits are either unquantifiable or only indirectly quantifiable in the context of a single unit of measure (e.g., dollars).

This does not mean that benefits may not exist. Implementation of pollution abatement may result in management changes which improve productivity or increase regional income, for example. The point is that cost-effectiveness analysis deals only with changes in input costs and output performance, not costs and benefits which, when evaluated using models like benefit-cost or internal rate of return, provide information relating to economic efficiency. Further, it would be incorrect to conclude that the net cost of pollution abatement is equal to the cost of input resources as used in the cost-effectiveness model.

Second, cost-effectiveness analysis is not resource allocation, which is concerned with the allocation of resources (time, manpower, money, etc.) among competing uses. The distinction is illustrated in Figure 10.

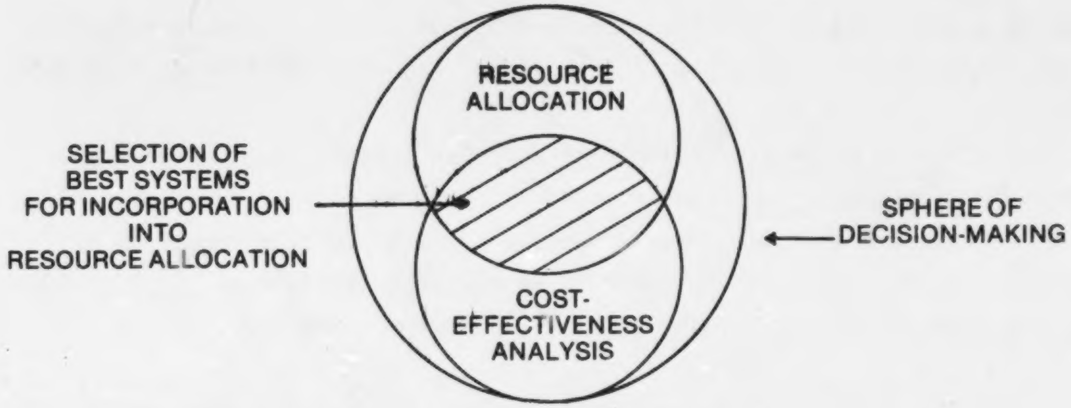

RESOURCE ALLOCATION
SELECTION OF BEST SYSTEMS FOR INCORPORATION INTO RESOURCE ALLOCATION
SPHERE OF DECISION-MAKING
COST-EFFECTIVENESS ANALYSIS

Figure 10. Relationship of cost-effectiveness analysis to resource allocation and decision making (after Kazanowski 1968, p. 117).

To continue the discussion of the forest manager, if his objective is to determine the extent to which he should concentrate his resources on erosion control as opposed to thermal problems (as well as reducing non-point water pollution in general) he has moved from the area of cost-effectiveness analysis to resource allocation.

These are separate kinds of analyses applied to different situations. However, in some instances the two analyses can be used in conjunction, as schematically shown in the figure above. In this case the decision might include the determination of the best erosion control strategy (cost-effectiveness analysis) in light of the total program for water pollution reduction (resource analysis).

In summary, cost-effectiveness analysis is an effective model for economic analysis of alternative erosion controls for silvicultural activities given the following conditions:

1. There is a specified performance level (erosion reduction standard) set as a goal toward which the effectiveness of a control can be measured. Cost-effectiveness analysis is predicated on the specification of this goal.

2. The benefits of erosion control arise largely from preventing off-site diseconomies or externalities relative to silvicultural objectives and are characteristically "public goods." These benefits (monetary or intangible) are implicitly assumed to be valued by society at least as much as the cost of the control and are not explicitly enumerated.

3. The unit for silvicultural management has a specified level of output (wood products, for example) measured as revenues or benefits. Since cost-effectiveness analysis deals only with costs, the benefit side (in terms of production) must remain relatively fixed as a point of reference during analysis.

4. The focus of attention is on the changes in cost of controlling erosion to improve water quality and the relationship between resource inputs and output performance, not on the economic efficiency of the entire operation.

....

The method for cost-effectiveness analysis involves a set of activities performed in sequence; its execution is a process. Following is a description of each of the steps in the process in the order they generally occur although the idiosyncrasies of any individual application may alter the sequence.

STEP 1. DEFINE OBJECTIVES

Identification of goals and definition of objectives is the most important aspect of any analysis. Problem identification is critical to defining the appropriate tool for analysis. Although specific objectives of cost-effectiveness analysis of erosion controls may vary with alternate applications of the model, the basic objective can be stated as--meeting a specified level of erosion control for non-point pollution abatement in a least-cost manner. The minimum level of effectiveness is generally assumed to be an expression of a standard.

STEP 2. ESTABLISH ALTERNATIVES

The second step entails determination of feasible erosion control strategies. This is a process of integrating the objectives of silvicultural management with the response by the site via its biological and physical attributes, and the available mitigative or preventive techniques for controlling erosion. Each of these conceptual strategies should meet or exceed the erosion control objective.

A meaningful comparison of alternatives requires the strategies to be significantly dissimilar so that a cost-effectiveness evaluation is warranted. Slight variations are not necessarily separate alternatives. Developing alternatives often calls for novel or innovative ideas, and in many cases an erosion control strategy will consist of a number of individual control practices. When comparing two such strategies composed of many of the same controls, focus should be on the cost-effectiveness of the differences between the two, with the similar aspects taken as equal and, therefore, not constituting a basis for making a decision.

The feasibility of various erosion controls frequently depends upon the scale of operation, the stage of the operation, and environmental conditions.

For example, small scale silvicultural operations are typically somewhat restricted in the availability of capital equipment; this in turn reduces harvesting options. In this case, then, erosion control opportunities arise largely from proper design and execution of activities. On the other hand, large scale operations, measured in such terms as volume, acreage, or expense, characteristically have greater access to capital goods and planning expertise. This broadens the range of erosion reduction options available.

The stage of the silvicultural operation also influences alternatives available for erosion control. The pre-implementation phase includes many options in the form of preventive measures. In contrast, operations which are currently on-going seldom present any but mitigative options.

Land type and precipitation patterns encompass most of the environmental conditions that influence the application of erosion controls. Local variations may be significant and the site of the silvicultural operation should be evaluated in terms of local environmental conditions.

STEP 3. ASSESSMENT OF EFFECTIVENESS AND COST

Once the various control strategies have been defined, both their costs and effectiveness must be determined. These two measurements should be broad enough to encompass the range of factors needed to evaluate each strategy. Their measurement may be simple or complex depending upon the complexity of the problem or the expertise of the user. This discussion focuses on the various attributes to be considered when measuring or evaluating both costs and effectiveness. Specific procedures for estimating either costs or effectiveness depend largely upon individual situations and should rely upon external assistance by technicians.

Step 3A: Effectiveness

Erosion is a complex process; its intricacies and the aberrations caused by silvicultural management are in the realm of hydrologists and soil scientists and are beyond the scope of this report. However, in order to conduct a cost-effectiveness analysis of erosion controls, it is necessary to define the information needed about the process. In the context of this report, effectiveness should embody a measurement of on-site soil loss as it relates to water quality. In some cases this may be directly quantifiable. In others, various attributes may need to be used as indicators of increased erosion; these generally arise from cause-effect relationships, and include the percent removal of forest canopy, degree of soil disturbance, number of miles of road, and so forth. Effectiveness can be a relative measure such as the percent reduction of the probable erosion without controls to the predicted erosion with controls, or it can be an absolute measure like kilograms of soil loss per hectare per year.

System effectiveness--

At this point in the discussion it becomes useful to develop the concept of "system" effectiveness. The effectiveness of most erosion controls, notably mitigative ones, is measured at the source. For example, installing water bars may be 80-percent effective in reducing erosion from skid trails in certain conditions. However, the impact of silvicultural management, a set of activities which interacts with the environment in many ways, is usually considered on an area basis--hence the concept of non-point source pollution. The point is, the measurement of a control's effectiveness should be representative of its contribution to the reduction of management impact rather than to a single source.

To illustrate, suppose a forest manager has conducted an appraisal of the impacts that are likely to occur from a silvicultural operation. He has determined that skidding logs to landings will contribute to approximately 20 percent the impact of the entire operation, the installation of the road system will account for about 50 percent of the entire impact, and other activities will account for the remaining 30 percent of the impact.

Previous research has shown that in these conditions water bars will reduce skid trail erosion by about 80 percent; and that proper installation of culverts, ditches, and energy dissipators in the course of road construction should reduce its impact by 50 percent. (This type of analysis should extend to all major activities and their impacts.)

On the basis of partial effectiveness alone, water bars would appear to be more effective in reducing erosion than would modifications in road design. However, in terms of system effectiveness, or by taking all activities, their respective impacts and the effectiveness of reducing these impacts by applying controls, road design modifications become more effective than water bars. This can be shown by using the simple relationship:

$$(L_1) \times (C_A) = E_1$$

where

L_1 = partial effectiveness of control number 1 for reducing the erosion impact of activity A;

C_A = contribution of activity A to total project impact;

E_1 = system effectiveness of control number 1.

In this example, the calculations are:

80% X 20% = 16% system effectiveness for water bars (or potential erosion reduced by 16%);

50% X 50% = 25% system effectiveness for road design modifications(or potential erosion reduced by 25%).

Time and system effectiveness--

Time may also be important when evaluating effectiveness. To include time in the analysis, a slight redefinition of system effectiveness is needed. This requires estimating the total project impact over the planning period (e.g., over a number of years) and also determining the portion of the total impact that occurs in each time segment (e.g., annually).

To illustrate, refer again to the example above involving water bars on skid trails. Partial effectiveness is 80 percent although the contribution of the skidding activity is 20 percent of the total impact of silviculture. Now, suppose this evaluation applies only to the first year of an operation that will continue over a period of 4 years. Further suppose, of the total project impact that occurs during the 4 years, only 10 percent of it occurs in the first year. By redefining system effectiveness of an erosion control in terms of the reduction in total impact that occurs over a number of years, the normalization formula becomes:

$$(L_{1,t}) \times (C_{A,t}) \times (I_t) = E_{1,t}$$

where

$L_{1,t}$ = partial effectiveness of control number 1 in year t;

$C_{A,t}$ = contribution of activity A to the project impact that occurs in year t;

I_t = portion of the total project impact that occurs in year t;

$E_{1,t}$ = year t effectiveness of control 1 for reducing total impact.

For year 1 in the example, the calculations are--

$$(80\%) \times (20\%) \times (10\%) = 1.6\%.$$

Given the conditions in the example, placing water bars on skid trails in the first year of operation will reduce the total 4-year impact on erosion by 1.6 percent, assuming weather conditions are similar over all years.

If the estimates are extended to each of the 4 years, the following tabulation can be developed.

Year	$L_{1,t}$	$C_{A,t}$	I_t	$E_{1,t}$
t = 0	80	20	10	1.6
1	50	30	40	6.0
2	40	20	30	2.4
3	30	20	20	1.2
				Σ = 11.2%

Total system effectiveness of an erosion control over time, then, is equal to the sum of the annual effectiveness measures. In this example, total system effectiveness of water bars on skid trails is 11.2 percent; this control would reduce erosion impact occurring over 4 years by 11.2 percent.

If time preference is important to the monetary aspects of erosion control decisions, discounting can be applied to the annual values (see the section "Cost" in this chapter for a discussion of discounting).

This example presents a simple approach to determining the effectiveness of erosion reduction techniques; its purpose, though, illustrates the concept of system effectiveness which must be incorporated into the analysis in order to make these measurements commensurable with project costs. Only when the data are normalized in this fashion is it correct to speak of cost-effectiveness criteria for evaluations.

. . . .

Many other factors could be taken into account when considering various aspects of effectiveness measurements. Some will be subjective and depend upon judgment or experience while others can be fully quantified. The major consideration is that the measurement of effectiveness must contain the information that is relevant to the criteria upon which the decision will eventually be made.

Step 3B: Cost

As a definition, cost is the measure of what must be given up in order to achieve something. Cost estimates need not be accurate to the last dollar, but an informed decision requires that cost information be accurate enough to be comparable to the measures of effectiveness. Frequently the actual and exact costs and effectiveness figures will not be known. A probable range, however, can frequently be agreed upon. Thus the cost and effectiveness components can be expressed in most probable ranges such as costs: $35-$50, the probability of cost being within this range is 90 percent (e.g., 10 percent of the time the costs will be higher or lower).

Application and performance of erosion controls are closely linked to on-site characteristics. Similarly, the relevant costs used in evaluating controls are those directly linked to the silvicultural activies on the site. Indirect costs stemming from erosion control which occur "off-site" (for example, loss of regional income or unemployment) are beyond the scope of this cost-effectiveness analysis method.

Costs can generally be classified into two distinct groups--outlays or opportunity costs.

Step 3B1: Outlays--

Outlays are the total money expenditures necessary to achieve a specified level of erosion control. Outlays can be classified in various ways. Identifying (a) the total incremental costs due to erosion control, (b) the portion of this increment that is composed of separable or traceable costs, and (c) the joint costs of the increment is the most useful procedure.

Incremental costs are the relevant costs for evaluating erosion controls that are related to non-point source pollution. As an example of determining incremental costs (following a discussion by Kemper and Davis 1976), assume a gross classification of management costs including harvesting, access, and cultural treatment costs. The computation for the net cost of erosion control becomes:

$$C = (H_i - H_s) + (A_i - A_s) + (T_i - T_s)$$

where,

C = the net or incremental cost of erosion control;
H_i = harvesting costs including erosion controls;
H_s = costs of commonly used harvesting practices;
A_i = costs of including erosion controls to access;
A_s = costs of providing "standard" access;
T_i = costs of cultural treatments including erosion controls;
T_s = costs of commonly used cultural treatments.

Actual applications of this technique will likely require greater disaggregation among costs.

Separable and joint costs for erosion control should be identified only for the incremental costs that arise in silvicultural management as a result of increased pollution abatement efforts. This focuses the analysis on the two major objectives--erosion control and silviculture. These costs are identified to facilitate cost accounting procedures. In this way costs can be allocated to their sources, such as labor, materials or equipment.

Separable costs can be directly traced to outputs--in this discussion, the output is erosion control. To illustrate, suppose an area that has been harvested is seeded with grass so that a protective cover is quickly established. The purpose of this activity is solely to reduce erosion and protect water quality until the forest crop becomes established. The cost (incremental to "usual" silvicultural management) of seeding the area, composed of the labor, equipment, and materials used, can be separated from the other silvicultural expenses. This total value is the cost of erosion control.

Joint costs are somewhat different. These costs are not directly traceable to any specific outputs--expenses are incurred that produce more than one output. Thus, the use of labor to produce erosion control may also produce another beneficial output, and the link between the costs and the individual outputs may not be directly traceable.

For example, suppose an access road is modified as a result of pollution abatement activities. Some construction expenses arise because the road itself must be protected from erosion. Other expenses are due to water pollution abatement. Although it may be possible to identify the separable costs for erosion control in general, it may be difficult if not impossible to separate the expenses directly related to erosion control for the purpose of water quality protection from the costs of protecting the road prism. This is a case of joint costs.

The difficulty with joint costs stems from the problem of identifying a realistic total cost figure. If the entire joint costs for erosion control were charged to pollution abatement in the example above, the total costs for pollution abatement would be overstated. Conversely, if joint costs were not included, the total cost would be understated. Since the true total cost of erosion control for water pollution abatement includes some portion of the joint costs, and yet the proportion is not directly separable, an additional method is needed to allocate the joint costs between the two outputs.

Several methods have been suggested. These include (a) relative sales value of production, (b) physical measurements of output, and (c) average unit cost method (Backer and Jacobson 1964). Since there are no direct revenues generated by erosion control, method (a) will not apply here. Method (c) does not involve directly tracing costs to specific outputs but rather calculates a unit cost for the production in general (in the example, it would simply be a unit cost for erosion control). It is suggested here that method (b) be used to allocate joint costs for erosion control.

Application of the cost allocation method based on measurements of outputs requires that the output units be specifically identified. As previously shown, the effectiveness of reducing accelerated erosion can be used to compare alternative controls. A similar measure could be developed for road prism protection as well. The joint costs could then be allocated on the basis of the ratio of the two effectiveness measures.

To illustrate, suppose that for the joint costs incurred in the example, erosion controls for the road protection are estimated to be 80-percent effective while the estimated effectiveness for water pollution abatement is 40 percent. The ratio of the two effectiveness measure is 2:1, which suggests that two-thirds of the joint costs should be borne as a cost of road protection while one-third of the joint costs is due to pollution abatement. By employing this method the portion of joint costs can be identified and added to separable costs to obtain a total cost figure that can be used in cost-effectiveness analysis.

Step 3B2: Opportunity Costs--

Opportunity costs present the second aspect of costs. In economics it is considered appropriate to define costs in terms of the value of alternatives foregone when achieving something (Bannock, Baxter, and Rees 1972). If the prices for the alternatives reflect their value, these costs are identical to outlays and should be treated as such. If the value for the alternatives are not reflected by their prices, as in the case of "public goods" (for example, water quality values affected by timber harvest), the opportunity cost measures the real sacrifice involved in the decision.

Step 3C: Time as a Major Component of Cost and Effectiveness--

Measurements for costs to this point have dealt with the static case; that is, time has not been thoroughly discussed. In order to evaluate long-term strategies for controlling erosion, the analytical framework must account for the effectiveness and costs that will exist in each time segment over the planning period. To accomplish this, two conditions must be met: first, the analyst must be able to estimate both effectiveness and costs for each time period as far into the future as the plan dictates. Second, a method must be available for weighing the importance of future costs or effectiveness relative to their occurrence in the immediate future.

Stream of costs and effectiveness--

To satisfy the first condition, estimates of cost and effectiveness can be made for each time period in the same fashion as outlined above. For each discrete time period (month, year, etc.) costs incurred and effectiveness gained can be estimated. These can, in turn, be arrayed to illustrate the stream of costs and effectiveness which will be encountered over time. For example, the cost estimates for two erosion controls over time might look like that shown in the tabulation below. Once the data are arranged in this manner, the second condition can be pursued.

	Year 1	2	3	4
Control X	$100	$ 10	$ 5	$ 0
Control Y	0	100	10	5

Discounting (the calculation of present value)--

The procedure for dealing with costs that occur in the future and the weighing of these against the present is well established in economic analysis. In fact, it is an economic axiom that costs incurred in the present are weighed more heavily than the same costs that might occur at some future date. Further, there is an inverse relationship between the weight placed on costs and the length of time between the present and the future date in question. This relationship is the basis of discounting or the calculation of present value.

For example, if the choice is to pay equal costs now or next year, the money could be placed in a bank to earn interest until next year and then be used to pay for the cost of control. Thus the rate of bank deposit interest would be a measure of the real value foregone (an "opportunity" cost) if the control costs were paid in the present rather than next year. Extensive literature exists concerning the debate on the choice of an appropriate discount rate (see Haveman and Margolis 1977). It will simply be noted here that the analyst should choose a discount rate that adequately reflects the relevant opportunity costs in his temporal analysis.

To illustrate an application of discounting, refer to the tabluation for the stream of costs for control X, shown above. In the current year costs amount to $100, $10 for the next year, $5 for the third year, and no costs encountered in the last year.

By utilizing the discount formula,

Present value of costs

$$= \sum_{t=1}^{4} \frac{100}{(1+0.5)^1} + \frac{10}{(1+.05)^2} + \frac{5}{(1+.05)^3} + \frac{0}{(1+.05)^4}$$

$$= 95.24 + 9.07 + 4.32 + 0.00$$

the present value of these costs amount to $108.63 at a discount rate of 5 percent. To compare the costs of controls when costs are distributed over time, the present value of costs are the only indices that should be used. These can be compared with discounted values for effectiveness when obtained as previously outlined.

Step 3D Choice of analysis technique--

The measurement of costs and effectiveness is conducted in the evaluation of each alternative. Once completed the analyst must make the choice between one of two approaches to cost-effectiveness analysis: fixed-cost or fixed-effectiveness. The choice must be made because cost-effectiveness analysis is used to evaluate the contribution of a program to a specified goal--either a budget constraint or a requisite level of effectiveness. The choice is non-trivial because both effectiveness and costs represent many variables as noted above.

The fixed-cost method usually relates to the objective of operating within a budget constraint. Effectiveness indices may include many factors, each evaluated with respect to the constrained level of cost. The alternative which produces the greatest degree of effectiveness given the fixed cost is usually preferred.

The *fixed-effectiveness* procedure is essentially the converse. A specified level of effectiveness is sought and alternatives are evaluated to determine the least-cost given this restriction. This will be the method most often employed in evaluation of erosion controls. Given the desired level of erosion reduction in any one time frame, the least-cost control is sought. It is still important, however, to remain sensitive to the choice between the two methods.

STEP 4. ANALYSIS

Analysis of the candidate programs for erosion control can proceed in various ways. The procedure employed often depends upon the specificity of the information available to make decisions and upon the relative magnitude of differences between the candidate strategies. There are basically two methods which are used to organize and analyze cost and effectiveness information. These are (a) *the model approach* which relies to a large extent upon mathematical relationships and (b) *the tabular display method* which is somewhat more subjective but also more versatile (Kazanowski 1968). Either of these methods, or some modification, can be employed in the analysis of erosion control programs. Each has its merits and the choice between either the model approach or the tablular display method largely depends upon the situation. Major commitments of resources, easily quantifiable evaluation criteria, small differences between alternatives and the availability of analytical expertise characterize situations where the development of a model would likely be warranted. In other cases where more subjective criteria become important it may be [illegible] the tabular format will more adequately serve as the analysis tool.

Model Approach

The *model approach* is generally used when the differences between choices are small, parameters of costs and effectiveness are easily quantifiable and other factors affecting choices are relatively unimportant or essentially identical among the alternatives. To develop a model, estimates of costs and effectiveness are made for each alternative. These estimates should include disaggregated costs for elements (labor, equipment, materials, etc.) as well as annual estimates for both costs and effectiveness. This information can be used later in project planning when the chosen control will be implemented. Both effectiveness and cost measures are then reduced to total value indices (present value if discounted) and these values represented in a coordinate system. The candidate programs can then be readily plotted using the estimated value of each index as shown for strategies A through D (see Figure 11).

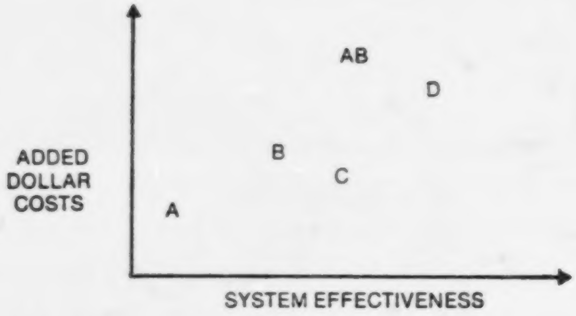


Figure 11. A simple cost-effectiveness model.

This simple example of the approach shown for illustrative purposes only, could easily be modified to incorporate more complex analysis. For example, various aspects of either costs or effectivenes (or both) could be represented by functional relationships or equations and incorporated into a multidimensional model rather than the graphical two-dimensional model shown above. Further, uncertainty over estimates could be introduced through the use of statistical measures of probability or dispersion. It may also be helpful to incorporate costs disaggregated by activity or their effects of change over time. In sum the model approach provides a broad range of analytical opportunities if the conditions for its application are met.

The greatest advantage to using the model approach is that many choices can be analyzed at once and with rapidity. However, there are also serious drawbacks in the method. First, models tend to be rigid, in that assumptions concerning various relationships are initially made, either implicitly or explicity. If an alternative subsequently requires analysis that conflicts with these assumptions, the model itself may require modification, often at the cost of the time and money. Second, a serious disadvantage is the necessity for simplifying assumptions. Both effectiveness and costs must be quantified and often expressed in a functional manner. Third, it is likewise necessary that the measures be commensurable. Aspects of the evaluation criteria that are not easily measured must either be discarded or further assumptions must be made about their imputed values. Considerable testing of the model may be required to validate the relationships among variables and their sensitivity to changes.

Tabular Display

An alternate approach for analyzing choices involves the use of a tabular display. By using this method, factors that affect decisions are not restricted to being quantifiable or commensurable. Figure 12 illustrates two tabular arrays. The array shown in (a) displays the basic components of the table. Decision variables are listed across the top of the table while alternative strategies to be considered are listed vertically. Information can be entered into the table either in a numerical or narrative format.

STRATEGIES	COSTS	EFFECTIVENESS
1 2 3 . .		

(a) The basic tabular form

STRATEGIES	COST COMPONENTS								EFFECTIVENESS		
	DOLLAR COSTS				SPECIAL EQUIPT.	SPECIAL SKILLS	OPPORTUNITY COSTS	REGULATIONS	SURFACE	SUBSURFACE	CHANNEL
	CAPITAL INVEST.	OPERATING COSTS		PLAN—NING							
		EQUIPT	LABOR								
1 2 3 . . .											

(b) A more detailed table (after Kazanowski, 1968)

Figure 12. An illustrative example of the tabular display.

The table shown in (b) is an embellishment of the basic array. Here, costs are decomposed into dollar (outlay) costs for various activities or components, opportunity costs, and into special requirements or other considerations. Likewise, effectiveness measures could be disaggregated to show the aspect of erosive action that is modified. Obviously, the possible modifications to the format are numerous and can be responsive to specific situations.

The tabular display relies more on judgment by the analyst than does the model approach with its strict mathematical relationships. There is, of course, the possibility for subjective bias, but if a consensus among several decision-makers is used, this outcome should be minimized. In comparison, the tabular display method mitigates many of the criticisms given the model approach. Although it is less objective, the tabular display also allows greater versatility for dealing with unquantifiable criteria like aesthetics which often enter the decision.

STEP 5. MAKING A CHOICE

With the completion of the preceding steps, the choice of the preferred strategy for controlling erosion must still be made. In order to do this, a firmly established criterion (or criteria) for choice must be used. The vital role this criterion plays in cost-effectiveness analysis is best illustrated by expanding upon an earlier example.

Consider the fixed-effectiveness model shown in Figure 13. Four alternatives for erosion control (A-D) have been identified, evaluated, and subsequently plotted on the graph. A fifth alternative, a combination of A and B, is also considered. The minimum level of effectiveness that is acceptable has also been identified and is shown by the broken line. The objective is to determine which of the alternatives is most cost-effective.

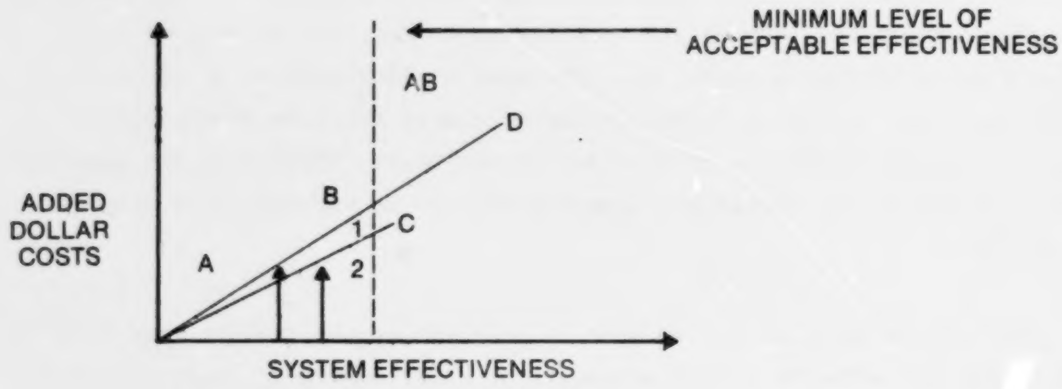


Figure 13. An illustration of a choice criterion.

Deductive reasoning provides some initial assistance. First of all, any alternative which does not provide the minimum effectiveness, or which lies to the left of the broken line, can be eliminated from consideration. Similarly, option AB is inferior to C and need not be considered further because although both C and AB provide the same level of effectiveness, AB costs more. The choice reduces to a selection between C and D with neither being clearly superior. This is where a specific criterion for choice is needed.

A criterion is a rule or standard which can be used to rank alternatives and to choose the most promising. In other words, it is a way to weigh costs against effectiveness. When using a model like the one shown in this example, the most prevalent criterion employed is the cost-effectiveness ratio, which is, in fact, a measure of marginal cost.

Returning to the example, the ratio can be illustrated by constructing rays from the origin to the points on the graph representing the alternatives. Angles 1 and 2 represent the cost-effectiveness ratios. The smaller the angle the greater the "cost-effectiveness" of the alternative. In this case the choice would be control program C. This choice of course implies that there is no budgetary constraint and that the objective is to minimize the ratio of costs to effectiveness. If, however, there had been a limit on the amount of additional costs that could be incurred so that it precluded the choice of D or AB on the basis of excess cost, the choice of C would have been obvious. As suggested above, this method is equivalent to choosing the alternative which minimizes the marginal cost of erosion control.

As one last point suppose that the cost-effectiveness difference between two alternatives is not very large, and/or given the probability approach, they may be reversed in a ration ranking. It will be desireable then to pick the alternative that has the greatest potential for greater effectiveness at the lower cost. Refer again to Figure 13. Although C is preferable to D for the given minimum acceptable effectiveness it cannot achieve as great effectiveness as D. If a decision was made to increase effectiveness at a later time, a cost solution greater than D would probably occur; i.e., the AB solution. Alternative D therefore presents an option for greater efficiency, and would be viable if the probabilities of cost between C and D overlapped.

A choice criterion applied in the case of the tabular display method is somewhat different than that used for the model approach. Since not all the information in a tabular display can be quantified, a cost-effectiveness ratio cannot be calculated. In this case, criteria concerning how information should be structured can be employed that will lead to a solution.

Returning to the sample table shown in Figure 12(b), the various factors underlying evaluations are listed across the top of the array. To form a basis for making a choice, it is suggested that these factors be arranged in decreasing order of importance from left to right. The alternative erosion control strategies should also be listed in order, vertically, beginning with the strategy which meets the most important (first) criteria to the greatest extent, and so forth. By arranging the table in this manner a number of alternatives can be evaluated and the best two or three identified. The ultimate selection is then generally based on a judicial evaluation with reference to the requirements of the situation and the objective of erosion control (Kazanowski 1968).

By relying upon clearly stated objectives and requirements developed in earlier steps, the possibility for subjective bias should be minimal. That is, given the goals of the analysis and the criteria to evaluate alternatives, there should be little disagreement about the solution.

. . . .

By following the steps outlined above and by using good quality information, the recommended choice for controlling erosion will be economically expedient. Even so, it is advisable to undertake two final tasks. It is always a good idea to re-examine the recommended program to assure its technical feasibility. This is highly important because of the wide variety of environmental conditions encountered in silvicultural operations. Second, the entire process (Steps 1-5) should be documented. This provides the decision-maker with a record of the assumptions, limitations, and conclusions the analyst encountered while producing his recommendation. These two final tasks round out the entire procedure for cost-effectiveness analysis.

CONCLUSION

Cost-effectiveness analysis, as discussed in this chapter, has demonstrated its usefulness for helping choose between alternatives that control erosion. It is certainly not the only economic model that is applicable to this kind of evaluation; even so, it includes basic economic principles, and although it can be readily adapted to many circumstances by modifications, the basic structure will not change.

Some of the limitations of the cost-effectiveness technique should be identified. (1) In some cases, reliance upon the ratio between costs and effectiveness as the sole criterion for choice is unwarranted. This stems from the fact that in the use of ratios, the actual magnitude of the numerator and denominator tends to be ignored. Even so, if magnitudes are arbitrarily limited, a selected alternative may be biased because of the limitation. Cases where ratios present the greatest problems are those that involve risk.

The magnitude of what is being risked has a bearing on the acceptability of the risk. The use of ratios ignores the effect of the magnitude of the risk, and hence its acceptability.

(2) Examples that have been used throughout this chapter to illustrate that certain aspects of cost-effectiveness analysis have been site-specific in their application. This is not intended to imply that cost-effectiveness analysis can only be applied to a geographic area of high resolution. Site-specific examples have been used to illustrate the close link between man's activities and the response by the environment. Larger scale applications are well within the realm of cost-effectiveness analysis. In fact, when very large geographic areas are considered, cost-effectiveness analysis may be one of a very few models that could be used.

As the geographic scale becomes larger, data regarding the environment and its response to manipulation tend to become more imprecise. Data are aggregated and specific responses are lost to average measures. In this case, uncertainty becomes a more important factor in both cost and effectiveness measurements. The cost-effectiveness model can certainly accomodate this, although the complexity of the estimating procedures is greatly increased and the precision of the estimates reduced.

As the scale of application increases, more tools may be needed to facilitate analysis. Multivariate statistical techniques may become valuable as cost or effectiveness estimating devices. Large numbers of alternatives may lend themselves to analysis by optimization techniques like linear programming.

(3) A final comparison between a site-specific application of cost-effectiveness analysis and one that is conducted for a larger area can be made. Applications involving large areas focus more upon determination of cost-effective programs of erosion controls and their scheduling rather than determination of the most cost-effective control among individual alternative controls. As the shift in emphasis is made from evaluation of individual controls on a site-specific basis to programs of controls at a regional basis,

the assumption must be made that the alternatives being evaluated are cost-effective. That is, when evaluating the cost-effectiveness of programs, the assumption is made that the controls that comprise the program have been previously subjected to cost-effectiveness evaluations.

. . . .

In retrospect, this chapter has presented a method for conducting a cost-effectiveness evaluation of erosion controls. The method has been geared to the specific requirements of conducting evaluations in forested environments. The procedure is not a compendium of all aspects of cost-effectiveness analysis, nor is it intended to be one. It has been presented here in an effort to provide an adequate guide for conducting a cost-effectiveness evaluation and to suggest ways to deal with potential problems. (The reader is referred to the various texts listed in the bibliography for specific or technical problems that may not have been included here.)

Finally, the application of the technique need not be overly complex to arrive at a good decision. As Kazanowski (1968, p. 139) puts it, it is "...preferable to use simple, understandable techniques to arrive at an acceptable near-optimum recommendation that is implemented rather than to use esoteric techniques to define a precise optimum recommendation that runs the risk of being relegated to dust-gathering because the responsible decision-maker(s) can neither follow nor comprehend the rationale underlying the techniques employed."

CHAPTER 4

APPLICATIONS OF COST-EFFECTIVENESS ANALYSIS

The previous chapter developed the basic concepts of cost-effectiveness analysis. This information was presented as a series of steps performed in the application of the method. These steps are shown in Figure 14.

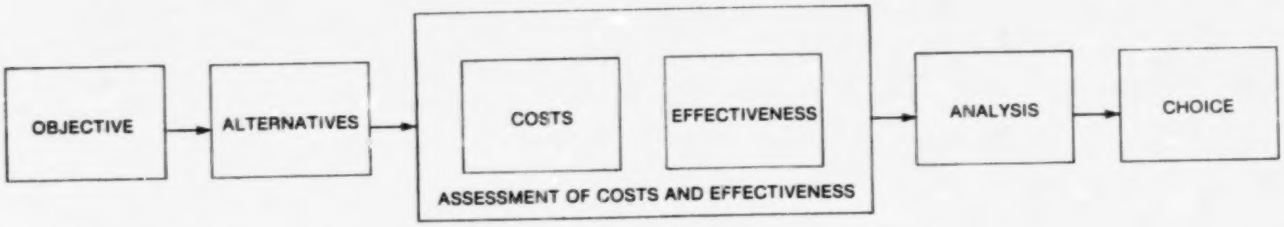
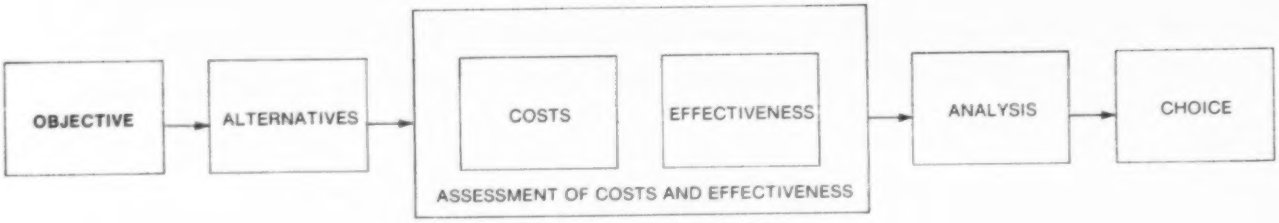

OBJECTIVE
ALTERNATIVES
COSTS
EFFECTIVENESS
ASSESSMENT OF COSTS AND EFFECTIVENESS
ANALYSIS
CHOICE

Figure 14. Cost-effectiveness flowchart.

This chapter illustrates how, with the assistance of some specific procedures, the cost effectiveness method presented in the preceding chapter can be used to choose erosion controls for silvicultural activities. First, a brief review of each step in the flowchart orients the user to the requirements of an application--what kinds of information are needed and where they can be obtained. Second, examples are presented which give the user an opportunity to see how the steps are executed and to note some of the limitations.

REVIEW OF THE STEPS

Step 1. Define the Objectives



This step defines the objective of the analysis toward which performance can be measured and in the pursuit of which costs are incurred. This requires familiarity with silvicultural activities themselves and their erosion impacts. In addition, a definition of the framework within which decisions will be made (applicable standards, regulations, budget levels, etc.) should be noted.

Another important component is determination of the scale at which the analysis will be conducted. As geographic scale increases to include a variety of environments, the objective and attendant information will become more general to reflect the increase in variation.

Information needs--

1. Performance of alternative controls (effectiveness) is measured relative to the objective. Thus, the objective must be specified in a manner that lends itself to measurement.

2. The objective should reflect the geographic scale at which the analysis will be undertaken.

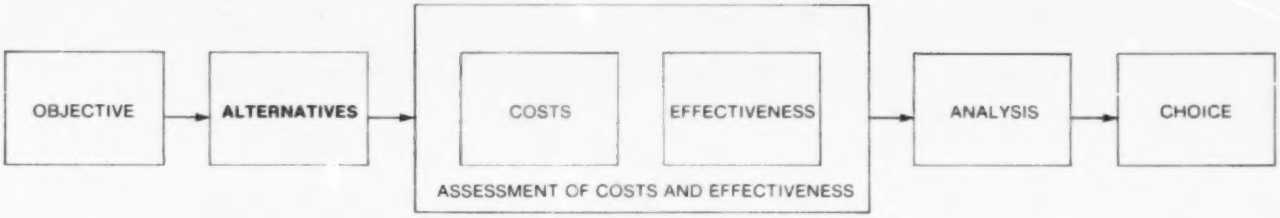
3. The objective should reflect both institutional and environmental considerations.

Information sources--

1. Legislation, regulations, and policies relating to water quality from Federal, State, and local government agencies (e.g., the Water Pollution Control Act Amendments of 1972, state water quality standards, local erosion control ordinances).

2. Technical assistance from government agencies, universities, research centers, private industry, and professional societies (e.g., the U.S. Forest Service, Soil Conservation Service, extension agents.)

Step 2. Establish Alternatives



Output from this step defines the opportunites for control that are available for attaining the objective. On a small scale, opportunities arise by employing individual mitigative and preventive controls. At a larger scale, opportunities involve combinations (strategies or programs) of controls that incorporate variations in environmental conditions.

Alternatives investigated are limited only by the prowess of the analyst, and the time and money available to him. Choices should not be limited to "business as usual." All opportunities for reducing erosion should be investigated.

Information needs--

1. To identify opportunities for controlling erosion, information should be obtained about the silvicultural activities and the environmental conditions within which they will take place. This information includes current silvicultural practices, proposed activities, and the manner in which the activities interact with the environment.

2. Environmental variations that represent opportunities for reducing erosion should be identified.

Information sources--

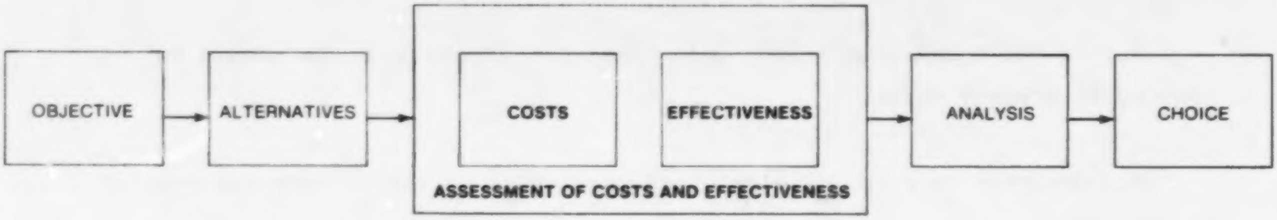
[illegible] Forestry-related technicians including foresters, hydrologists, engineers, extension agents.

2. Research organizations like universities, government research institutes, professional societies.

3. Technical literature, (e.g., *Water Resources Research*, *Journal of Forestry*, *Journal of Soil and Water Conservation*, *Land Economics*).

4. New technology, (e.g., trade journal reports on new products, U.S. Forest Service Experiment Station Reports.)

Step 3. Assessment of Costs and Effectiveness



This step is integral to the successful application of cost-effectiveness analysis. Choices are made almost exclusively on the basis of the attributes measured in this step. Therefore, they must include the range of information relied upon to produce a decision.

Measuring effectiveness of a control requires technical procedures and expertise. These technical procedures are beyond the scope of this report. It is stressed that the measurements of effectiveness must be commensurable with the objective so that performance can be calculated.

Methods for cost assessment were presented in the previous chapter. The required index of cost must include the total cost of erosion control related to non-point source pollution abatement. In terms of management cost, it is the *increment to total costs* that can be related to erosion control, beyond "usual" operations. These costs are composed of outlays and opportunity costs and may occur over time as well.

Information needs--

1. Whenever it is possible, the incremental erosion control costs incurred for the purpose of abating pollution should be distilled from other costs that arise from silvicultural management.

2. To obtain a total erosion control cost, both joint and separable costs must be identified in the accounting framework. Allocation of costs to factors of production (labor, equipment, materials, etc.) is also useful information and should be accounted.

3. If there are commitments over time, the stream of costs should be reduced to present value.

4. Opportunity costs are important components of total costs and should be included.

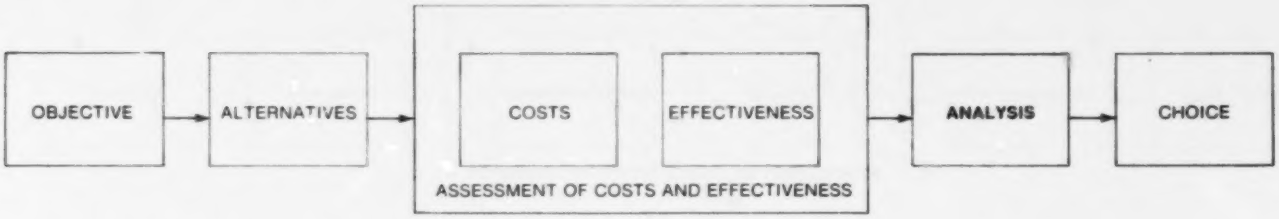
5. Performance should be measured as system effectiveness to assure commensurability with costs and the objective.

Information sources--

1. For information on the effectiveness of controls refer to specialists such as foresters, hydrologists, and engineers who are familiar with the various techniques for evaluating erosion controls in the forested environment.

2. Cost-estimating guides can be obtained by referring to private contracting and consulting firms, professional societies, libraries, and government agencies (USDA Forest Service, State highway departments, county extension agent, among others).

Step 4. Analysis



Analysis uses the information obtained in previous steps and evaluates it with regard to the objective. The form which the analysis takes depends on the information that is included in the decision criteria. If information is quantifiable, the model approach is a good choice. If information is less rigorously defined and includes subjective evaluation factors, the tabular display becomes more applicable. Choice between the fixed-cost or fixed-effectiveness models depends upon the framework within which the objective was defined. Extensions of analysis to include statistical cost estimating procedures or sensitivity analysis, for example, are at the discretion of the user.

Information needs--

1. Information on costs and effectiveness as well as the objective must be reviewed to determine the best approach (model or tabular).

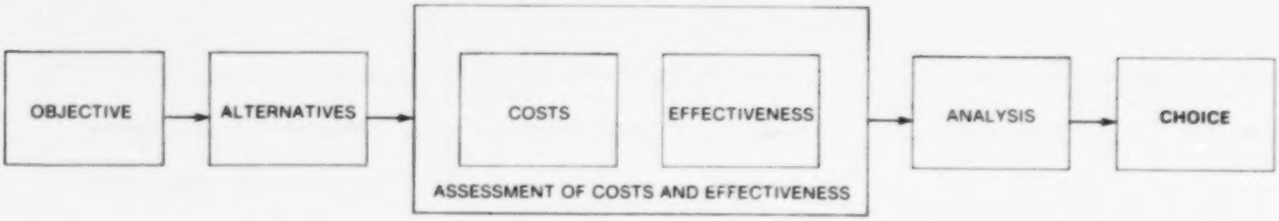
2. Review constraints on budget or performance (or both).

3. Additional decision criteria should be reviewed.

Information sources--

Refer to previous steps.

Step 5. Choice


OBJECTIVE
ALTERNATIVES
COSTS
EFFECTIVENESS
ASSESSMENT OF COSTS AND EFFECTIVENESS
ANALYSIS
CHOICE

The final step involves choice of the most cost-effective control(s). As described in the previous chapter, some alternatives can be intuitively eliminated, while the choice between remaining alternatives may require a criterion to rely upon. Following a choice, it is advisable to review the selected alternative for technical feasibility.

Information needs--

If a choice criterion is used (such as a ratio or a preference consensus), the criterion itself and how it applies to decision-making should be explicitly stated.

EXAMPLE 1. COST-EFFECTIVENESS ANALYSIS APPLIED TO CONTROL SELECTION ON A SINGLE SITE

Construction and maintenance of access roads to silvicultural operations in the lodgepole pine type of the central Rocky Mountains can involve erosion hazards, but controls can be applied to these activities that reduce erosion and protect or improve water quality.

Step 1. Define Objective

A silvicultural operation was proposed for a lodgepole pine stand. The forest manager evaluated the site and its relationship to the surrounding environment; he consulted with water quality planners and reviewed local regulations. As a result, he concluded that the erosion-control objective was to reduce the total expected erosion impact over the next 4 years by 40 percent. This will keep the project impact well within the acceptable limits throughout the duration of the project.

In steps 2-5 of this example access activities are examined and erosion-reduction measures which must be employed to meet the objective with controls only on access activities are determined. Step 6 expands the analysis to determine cost-effective alternatives for all erosion-control practices.

Step 2. Define Alternatives

Consultation with the road construction engineer yielded a description of the access activity and the erosion hazards involved. On this site, road sections occurred predominately on 50-percent side slopes (Figure 15). The running surface was 14 feet, with a 2-percent outslope. Most road construction was to be completed in the first year, harvesting and site treatments throughout the following 3 years, with project completion in the fourth year.

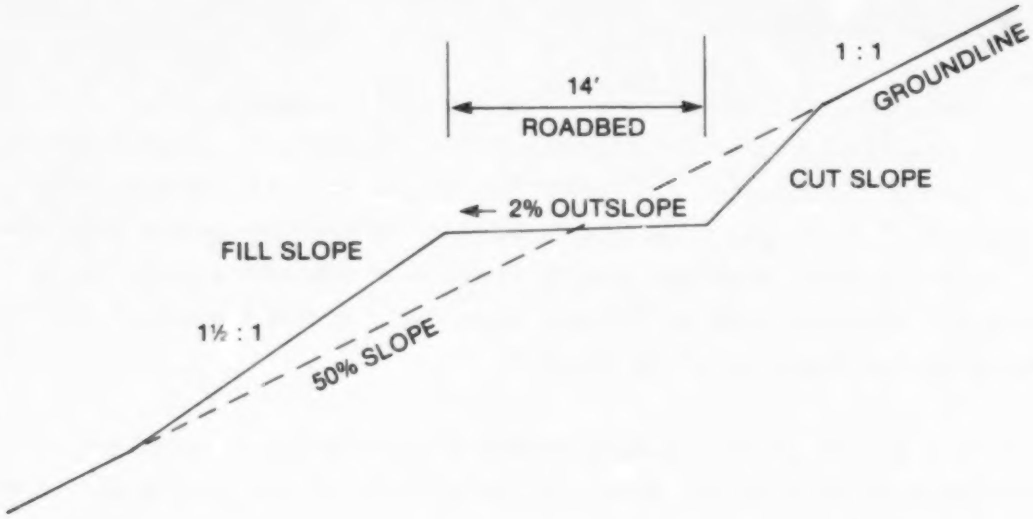

14'
ROADBED
1 : 1
GROUNDLINE
CUT SLOPE
← 2% OUTSLOPE
FILL SLOPE
1½ : 1
50% SLOPE

Figure 15. Cross section of a roadbed.

Step 2A. Estimate Erosion from Major Source Areas--

With respect to the access activity on this site, erosion could occur on the fill slope, the cut slope, and the road surface. Estimates by the engineer for the erosion from these areas over the planning period are shown in Table 9.

TABLE 9. ESTIMATED EROSION FROM SOURCE AREAS*

Source Area	Year				Total
	1	2	3	4	
	--Tons per mile--				
A. Cut Slope	75	60	40	25	200
B. Road Surface	25	25	25	25	100
C. Fill Slope	90	80	80	50	300

*NOTE: These figures are exemplary only and are not intended to be representative of any area.

Step 2B. Determine Appropriate Erosion-Control Practices--

As a result of their knowledge about both the site and the erosion hazards, the engineer and forest manager were able to determine erosion-control practices best suited to mitigating specific erosion hazards (Table 10).

TABLE 10. EROSION CONTROL ALTERNATIVES

A. Surface erosion from cut slope[1]
  1. Grass seed
  2. Grass seed and fertilizer
  3. Grass seed, fertilizer, mulch
  4. Grass seed, fertilizer, jute mat

B. Surface erosion from road surface
  5. Close road between uses
  6. Close, seed, fertilize
  7. Gravel the surface
  8. Asphalt surface on base

C. Surface erosion from fill slope[1]
  9. Grass seed
  10. Grass seed and fertilizer
  11. Grass seed, fertilizer, mulch
  12. Grass seed, fertilizer, jute mat

---

[1] Cut slope and fill slopes are 1:1 and 1-1/2:1, respectively (see Figure 16, p. 76).

Step 3. Assessment of System Effectiveness

Step 3A. Calculate Local Effectiveness of Alternative Controls--

Partial effectiveness of individual controls were estimated by the forest manager who consulted the engineeer, computer models of erosion processes, past records, and an evaluation of specific site conditions. Partial effectiveness estimated were made for each year of the 4-year period and they refer to the effectiveness of the control for reducing erosion on the local source, i.e., the cut slope (this information is shown in Table 11, p. 68).

TABLE 11. TOTAL SYSTEM EFFECTIVENESS OF CONTROLS*

Calculation:	(Step 3A) ×	(Step 3B) ×	(Step 3C) =	(Step 3D)
Alternatives†	Partial Effectiveness‡	Local Source Contribution§	Activity Contribution¶	System Effectiveness
A. Cut Slope				
1	10	33	75	2
2	20	33	75	5
3	30	33	75	7
4	50	33	75	12
B. Road Surface				
5	15	17	75	2
6	25	17	75	3
7	80	17	75	10
8	98	17	75	12
C. Fill Slope				
9	20	50	75	8
10	40	50	75	15
11	75	50	75	28
12	90	50	75	34

---

* All figures in percent.

† Numbers refer to alternative controls shown in Table 10.

‡ Total effectiveness over the 4-year period.

§ Based on estimated 150 tons/mile/year for a road section divided among the cut slope, fill slope, and road surface.

¶ Proportion of total impact due to access activities.

Step 3B. Estimate Percentage Contribution of Erosion on Single Source Area to Total Contribution of Erosion of All Source Areas--

Erosion from any single source, (i.e., cutslope), must be computed in relation to erosion from all source areas, e.g., cut slope + road surface + fill slope (see Table 11, p. 68). For example, total erosion over the 4-year period for cut slopes was 200 tons/mile (see Table 9). For all areas, it was 600 tons/mile. Therefore, the percentage contribution of erosion from the cut slope to erosion from all source areas was 33 percent, or 600/200.

Step 3C. Estimate Contribution of Activity to Total Project Impact--

Normalizing these estimates to a measure of system effectiveness requires an estimate of the contribution of the local source to the total impact of the project. Table 8 in Chapter 2 suggests that in Ecoregion 3100 roads involve the greatest hazard, although the absolute share due to this activity is not indicated. This can only be evaluated by an investigation of site conditions for the area where the silvicultural activity is proposed.

By evaluating the site conditions and comparing them with other silvicultural operations in similar conditions, the impact due to access activities over the planning period were estimated to be:

	Year				Total
	1	2	3	4	
Access	30%	20%	15%	10%	$\Sigma=75$

Thus, the impact of access activities were estimated to account for 75 percent (e.g., 30 + 20 + 15 + 10) of the total erosion impact over 4 years. No discounting was applied to effectiveness values (see Table 11, p. 68).

Step 3D. Calculate System Effectiveness--

With information gathered from Steps 3A through 3C, calculations to determine system effectiveness were carried out (see Table 11). For example, Control 2 has a 5-percent system effectiveness; this was calculated 20% x 33% x 75%.

Step 4A. Assessment of Costs

A standard accounting framework was used to develop each of the total cost estimates. In this case the framework is shown with entries for one of the controls (Table 12).

TABLE 12. A STANDARD ACCOUNTING FRAMEWORK APPLIED TO CONTROL 11

	Unit Cost	Units/Mile of road	=	Direct Costs Hydroseed and Mulch	
Labor					
Man hours	$8.00	8		$64.00	$64.00
Materials					
Seed (cwt)	26.00	8		208.00	
Fertilizer (ton)	72.00	1-1/4		90.00	
Mulch (ton)	150.00	3		450.00	748.00
Equipment and Overhead					
Hydroseeder (hr)	70.00	4		280.00	
Overhead (hr)	65.00	4		260.00	540.00
TOTAL DIRECT COSTS					1,352.00
TOTAL JOINT COSTS					422.00
TOTAL COSTS					1,774.00

A total discounted cost value must also be determined (Table 13). This requires that the costs be estimated for each time period so that discounting can be applied. Costs were derived using a standard cost estimating guide for road construction. They represent costs attributable to erosion control for water pollution abatement. Total cost figures appearing in Table 14, p. 73 are the discounted values from each time period. A discount rate of 7 percent was applied.

TABLE 13. MULTI-PERIOD COSTS ATTRIBUTABLE TO EROSION CONTROL FOR WATER POLLUTION ABATEMENT

Control	Year: 1	2	3	4	Total Cost*
A. Cut Slope					
1	$ 172				$ 172
2	287				287
3	747				747
4	5,853				5,853
B. Road Surface					
5				$375	306
6				890	726
7	8,000	$200	$200	200	8,525
8	30,500	200	200	200	31,025
C. Fill Slope					
9	409				409
10	682				682
11	1,774				1,774
12	13,896				13,896

---

*Cost per mile of road discounted at 7 percent.

Step 4B. Determine Best Combination of Erosion Controls

Table 10 (p. 66) shows the individual controls that apply to different areas, but combinations of these controls could also be applied and should themselves be considered alternatives. All possible combinations of controls could feasibly be enumerated. In order to reduce the combinations that required analysis, two steps were taken:

(1) It was noted that the controls applied to any single area (i.e., cut slope) were generally combinations themselves (i.e., grass seed, fertilizer jute mate; grass seed and fertilizer). Thus any combinations of controls could only include one choice from the set of controls that apply to any area--for example, only one of the four controls that apply to the cut slope sould be included in a combination of controls.

(2) In order to reduce the number of combinations needing evaluation, any combination of controls that was less than 40-percent effective was not enumerated; nor any controls that were greater than 45-percent effective.

Since effectiveness and cost figures were estimated, it was assumed that the values for combinations were additive. That is, a combination of controls 1 and 5, for example, would have a cost of $478 with an effectiveness of 4 percent. Table 14 summarizes the control alternatives, including possible combinations their costs and effectiveness.

TABLE 14. SUMMARY OF EROSION CONTROL ALTERNATIVES

Alternative[1]	Cost/Mile	System Effectiveness	Ratio ($/%x100)
A. Cut Slope			
1	$ 172	2%	86
2	287	5	57
3	747	7	107
4	5,853	12	488
B. Road Surface			
5	306	2	153
6	726	3	241
7	8,525	10	853
8	31,025	12	2,585
C. Fill Slope			
9	409	8	51
10	682	15	45
11	1,774	28	63
12	13,896	34	409
D. Combinations			
12 + 7	22,421	44	510
12 + 3	14,643	41	354
11 + 4	7,627	40	191
11 + 8	32,799	40	820
12 + 6 + 3	15,369	44	349
12 + 6 + 2	14,909	42	355
12 + 5 + 3	14,949	43	348
12 + 5 + 2	14,489	41	353
11 + 8 + 2	33,086	45	735
11 + 8 + 1	32,971	42	785
11 + 7 + 3	11,046	45	245
11 + 7 + 2	10,586	43	246
11 + 7 + 1	10,471	40	262
11 + 6 + 4	8,353	43	194

---

[1] Numbers refer to alternatives listed in Table 10.

Step 5. Analysis and Choice

Step 5A. Calculate Cost-Effectiveness Ratios--

To determine the most desirable control strategy in terms of the objective, cost-effectiveness ratios were calculated for each control and control combination. These are derived by dividing costs by effectiveness. (Ratios are shown in Table 14.)

Step 5B. Determine Best Alternative For Reducing Erosion for Specificed Level of Effectiveness

Using the lowest ratio as the criterion, the best choice for reducing erosion by 40 percent was:

Control 11: grass seed, fertilizer, and mulch on the fill slope

plus

Control 4: grass seed, fertilizer, and jute mat on the cut slope.

This combination was 40-percent effective over 4 years and had a total discounted cost of $7,627 per mile of road.

A sensitivity analysis is another means of showing how responsive total costs are to various levels of erosion-control effectiveness. To facilitate analysis, the most cost-effective control(s) was determined for cost-effectiveness levels 5 through 55 percent at 5 percent increments. This analysis included: (1) determining which controls or combinations met the effectiveness level, for example, 5 percent (see Table 14); and (2) evaluating these alternatives on the basis of their respective cost-effective ratios (see Step 5A or Table 14) to determine the cost-effective choice. The results of these analyses are shown in Table 15. Using 5 percent increments is purely illustrative of a sensitivity analysis procedure. It should be noted that in this example although access activities account for 75 percent of the project impact, a maximum of only 58 percent of the impact could be mitigated using the controls available, and at a cost per mile of $50,774.

TABLE 15. TOTAL COSTS OF EROSION CONTROL FOR ACCESS ACTIVITIES

Alternative	Step 3D Approximate Level of System Effectiveness	Step 4A Total Cost per mile of need
2	5%	$ 287
10	10	682
10	15	682
10+2	20	969
11	25	1774
11+1	30	1946
11+3	35	2521
11+4	40	7627
11+7+3	45	11046
11+7+4	50	16152
12+7+4	55	28274
12+8+4	58 (maximum possible)	50774

Figure 16 is a graph of the information shown in Table 15. This cost curve shows erosion control costs for access activities on this site for various levels of erosion impact reduction when cost-effective alternatives are used.

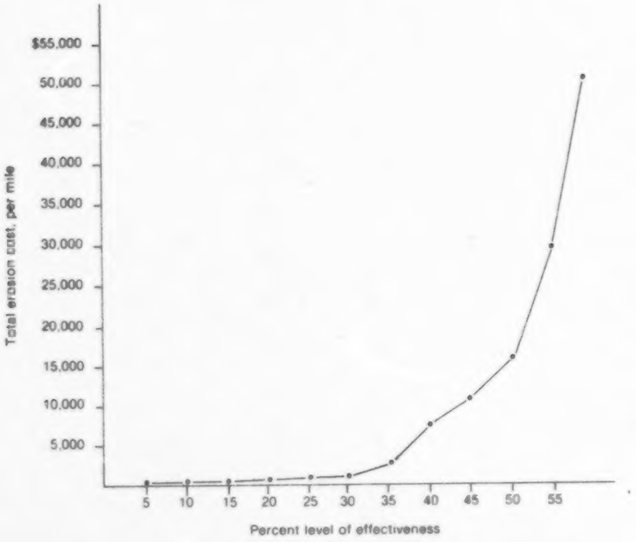


Figure 16. Total cost for erosion control for access activities.

Step 6A. Expand Analysis to Determine Cost-Effective Alternatives for All Erosion-Control Practices

At this point the analysis was expanded to include not only access activities, but analysis of erosion control alternatives for harvest and cultural treatments as well. To determine the best strategy for the harvest area as a whole, it would be possible to simply include the controls for harvest and cultural treatment activities as further alternatives that could be combined with access controls. The analysis could then proceed as outlined above for access activities only.

In this case, the analysis was done a little differently. The most cost-effective controls for various levels of effectiveness were determined, but for access, harvest, and cultural treatment activities separately. These results appear in Table 16 (note that costs are now comparable on a per acre basis).

TABLE 16. COST-EFFECTIVE ALTERNATIVES FOR ALL FORMS OF EROSION CONTROL

Step 6A	Step 6A Level of Effectiveness	Step 6A* Total Cost	Step 6B Marginal Cost	Step 6B Rank
	%			
A. Access				
1.	5	$ 1.32	$ 1.32	1
2.	10	3.20	1.88	2
3.	15	3.20	---	3
4.	20	4.54	1.34	4
5.	25	8.32	3.78	6
6.	30	9.12	.80	7
7.	35	11.82	2.70	8
8.	40	29.79	17.97	9
9.	45	51.78	21.99	10
10.	50	75.71	23.93	11
11.	55	132.53	56.82	14
12.	58	238.00	105.47	15
B. Harvest**				
1.	5	43.00	43.00	12
2.	10	56.00	13.00	13
C. Cultural Treatments**				
1.	5	2.00	2.00	5

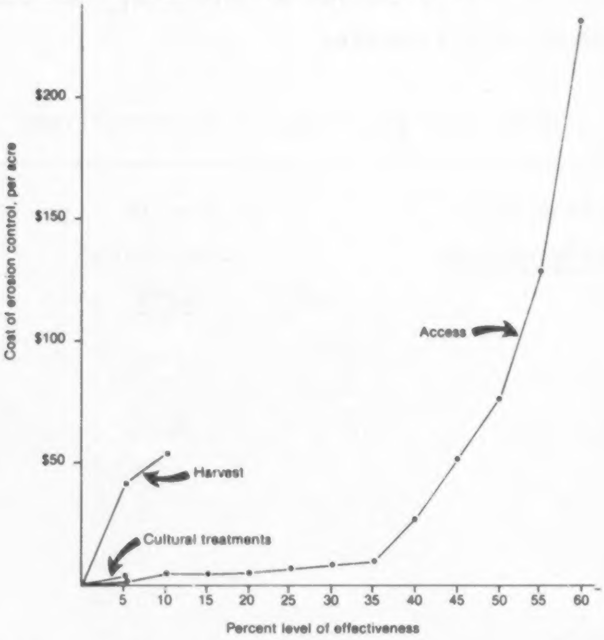
---

*Cost per acre of harvested area; it was assumed that these were 3 miles of road per section (640 acres) of harvested area.

**Harvest activities were estimated to account for 15 percent of the total four-year impact; cultural treatments for 10 percent.

Just as a total cost curve relating costs to various levels of effectiveness was developed for access controls only (see Figure 16), three curves were developed showing total costs for each of three activities. This is shown in Figure 17, and was developed using the information from Table 16.

Figure 17. Total Cost Curves for All Activities.



Using this kind of information, a sensitivity analysis can be undertaken to determine a cost-effective strategy for erosion control in general, including control possibilities for all three kinds of activities.

Step 6B. Calculate Marginal Costs for All Erosion-Control Alternatives in Order to Rank Alternatives

The marginal cost, or the additional cost at an increment of 5-percent effectiveness, were calculated for each alternative. The alternatives from all activities were then ranked in order of increasing marginal cost (with the rule that alternatives from any activity must be sequential--i.e., alternative 5 for access must come before alternative 6). The last column in Table 16 shows this ranking.

Step 6C. Estimate Total Costs in Relationship to Levels of Effectiveness

Using the ranking (Table 16), a final table can be constructed to show the strategy as it relates to various levels of effectiveness. Table 17 shows the levels of strategy effectiveness (cumulative effectiveness), the costs of the strategy (cumulative cost), and the alternatives that comprise the strategy for a level of effectiveness.

TABLE 17. TOTAL COST RELATIONSHIP TO EFFECTIVENESS LEVELS

Step 6C Rank	Step 6C Alternatives	Step 6C Cumulative* Cost	Step 6C Cumulative Effectiveness Percent
1	(A-1)	$ 1.32	5
2	(A-2)	3.20	10
3	(A-3)	3.20	15
4	(A-4)	4.54	20
5	(C-1)	6.54	25
6	(A-5)+(C-1)	10.52	30
7	(A-6)+(C-1)	11.12	35
8	(A-7)+(C-1)	13.82	40
9	(A-8)+(C-1)	31.79	45
10	(A-9)+(C-1)	53.78	50
11	(A-10)+(C-1)	77.71	55
12	(A-10)+(C-1)+(H-1)	120.71	60
13	(A-10)+(C-1)+(H-2)	133.71	65
14	(A-11)+(C-1)+(H-2)	190.53	70
15	(A-12)+(C-1)+(H-2)	296.00	73

---

*Cumulative total of marginal costs.

The information in the table can be transferred to a graph to illustrate the total cost relationship in effectiveness levels. This is shown in Figure 18.

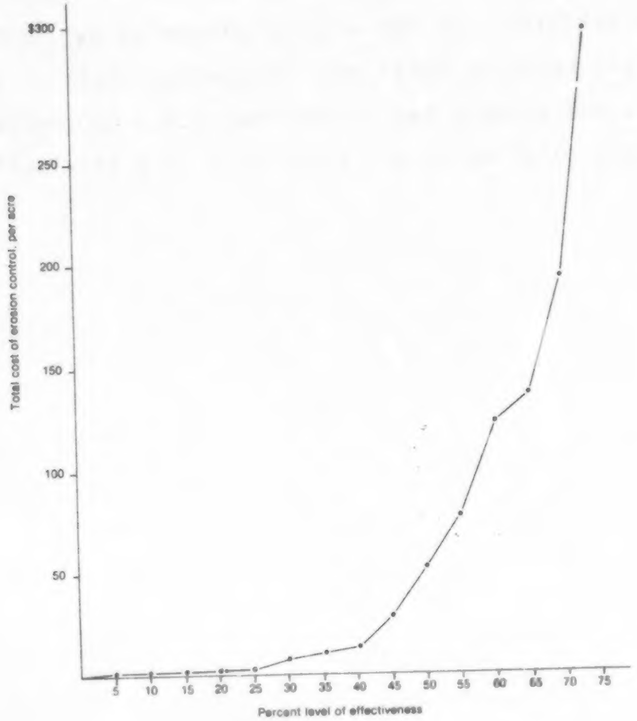


Figure 18. Total cost for erosion control.

As shown by the curve, a maximum of 73 percent of the erosion impact of the project could be reduced by applying the most effective controls, although this would cost about $296 per acre. The graph clearly illustrates how costs increase with higher levels of control. Notably, costs begin to escalate dramatically above a 40 percent reduction.

SUMMARY

This example has shown, first, how individual controls can be evaluated. Second, it demonstrates how controls can be combined into further alternatives and how a cost-effective choice can be made from all of these in relation to one silvicultural activity. It has also displayed an application of sensitivity analysis relating total erosion-control costs to various levels of control. Finally, the example has illustrated how a cost-effective choice can be made for controls relating to all activities in a silvicultural operation.

EXAMPLE 2: CHOICE OF PREVENTIVE EROSION CONTROL FOR MECHANICAL SITE PREPARATION IN THE SOUTH

This example applies cost-effectiveness analysis to a situation in which not all cost or effectiveness measurements can explicitly be made. Opportunity costs not directly measurable in dollar terms are included in the analysis, and to accomodate these a tabular display is used. Further difficulty in determining the portion of total costs due to erosion controls necessitated the use of only management costs--a problem that can often be encountered.

Objective

Some sort of mechanical site preparation is usually required to establish a well-stocked plantation with superior trees. Erosion rates can be high during some mechanical site preparation procedures, and the main control will be that of maintaining or creating vegetative ground in the treated area, plus leaving a streamside management zone. The type of mechanical site preparation is governed by both the tree species to be planted and the size and amount of residual stand after clearcutting. In this example, loblolly pine is being planted in the upper coastal plain in an area having a residual hardwood stand of about 6 inches in diameter. The landowner wants to establish a well-stocked plantation with minimum investment and he needs to cut the present erosion rate in half--to approximately 6 tons per acre per year. The 6-ton erosion rate coupled with a streamside management zone that is 90-percent effective will reduce erosion to acceptable levels.

Alternatives

The landowner has several alternatives to choose from, but some of them have environmental tradeoffs. He can choose from two commonly used site preparation treatments: (1) To fell the residual hardwoods with a KG shearing blade, rake the debris into a windrow and burn it (which would affect air quality), and machine plant at a cost of $90 an acre. With this procedure the erosion rate is expected to be about 13 tons per acre per year; or (2) To shear, rake and windrow, disk, and machine plant at a cost of $112 per acre, with erosion reduced to 10 tons per acre per year.

Neither of these alternatives meets the 6-ton criteria however; as a consequence the usual site preparation treatment must be modified. This will lead, in turn, to other alternatives:

(3) To shear, rootrake and windrow, machine plant, and seed with grass at a cost of $110 per acre and an expected erosion rate of 4 tons per acre per year. However, costs will remain relatively high and there will be some reduction in tree seedlings survival and reduced timber yields per acre.

(4) To shear and hand plant provided planting crews are available; and during the second year, release spray with herbicides for a total cost of $66 per acre (present value). The erosion rate is expected to be approximately 3 tons per acre per year. However, there is a tradeoff between erosion control and introduction of herbicides into the forest environment which could, in turn, have a water quality impact.

(5) To shear, chop, burn, and hand plant would cost $81 per acre with erosion expected to be 3 tons per acre per year. Prescribed burning, as with release spraying, minimizes the vegetation that competes with seedlings. However, burning would impact air quality and some ash could enter the stream.

(6) A final alternative would be to use the seed-tree harvesting system--scarify the soil, use hand injection of herbicides to kill the residual hardwood and thin the natural regeneration at the age of 4 to 5 years. Trade-offs include (a) the dead hardwoods left standing would adversely affect aesthetics and (b) the resulting stand of pine would not be of superior tree stock, resulting in a 20- to 25-percent reduction in production. The erosion rate would be about 3 tons per acre, and the treatment would cost (at present value) $65 per acre.

All of the above alternatives are technically possible provided that hand planting crews, spray equipment, and mechanical site preparation equipment are available. But in many areas hand planting cannot be used because of the scarcity of labor crews.

Analysis in this case utilizes the tabular display (Figure 19). Alternatives are presented in descending order of preference, depending upon subjective weights placed upon the various aspects of effectiveness and costs, based on the judgement of several individuals. In this case, the preference rankings are not entirely related to dollar costs. An important consideration is in the trade-offs indentified for each alternative. The preferred alternative is shown as number (1).

As a matter of contrast to the alternatives presented, on hardwood stands less than 4 inches in diameter, a simple drum chop and hand planting could have been used, followed by release spray at a cost of $54 per acre and an erosion rate of 1 ton per acre per year. This demonstrates that the size of the residual stand has a marked impact on site preparation treatment, the resulting erosion rate, and the cost of tree planting. With the use of prescribed burning during the rotation, future plantations could be re-established using this type of treatment or something similar in intensity, because the hardwoods will be kept small enough that a light treatment can be used. Intensely prepared sites are the result of two factors: Forest stands now contain large hardwoods and many more forest stands are being brought under management.

STRATEGIES	COSTS			EFFECTIVENESS
	Cost per acre[1]	Special Requirements	Trade-offs	tons/acre/year
(1) Shear, hand plant and release spray with herbicide in the second year	$ 66	a) Planting crews b) Spray equipment	Herbicide use	3
(2) Shear, chop and burn, and hand plant	81		Burning may affect air	3
(3) Seed tree harvest, scarify soil, hand injection of hardwoods, thin at 4-5 years	65		a)Unsightly dead trees b)No superior tree stock c)Reduced yields by 20-25 percent	3
(4) Shear, root-rake, windrow, seed with grass, machine plant	110		a)Reduced seedling survival b)Reduced timber yield	4
(5) Fell hardwoods with a KG blade, rake into windrows, burn, machine plant	90	Special equipment needed	a)Air quality affected b)Size of residual trees limiting	13
(6) Shear, rake, windrow, disk, machine plant	112	Special equipment needed		10

[1] present value discounted at 7%

Figure 19. Tabular Display.

EXAMPLE 3. LARGE AREA ANALYSIS

This example uses cost-effectiveness analysis to evaluate erosion-control strategies that apply to extensive areas. This is in contrast to the previous two examples which determined a cost-effective strategy for reducing erosion in an area generally homogenous with respect to erosion response to management activities. As scope of analysis broadens in a geographic sense, environmental variety increases and erosion responses to silvicultural management may differ. For example, within a river basin of several thousand acres, a number of forest types can occur, and silvicultural management in each will likely produce different erosion responses.

Cost-effectiveness analysis applied to large areas shifts its emphasis from choice between individual controls for specific areas to choice between erosion control strategies that apply to entire segments of a region. Example 1 produced an erosion control strategy for given conditions in the central Rocky Mountains. On a large area basis, this strategy would become only one of the many alternatives relating to other sites. In general, the problem at the large scale is one of evaluating alternative strategies, made up of cost-effective combinations of individual controls, which can be combined to produce a cost-effective erosion reduction program.

Step 1. Determine Objective

This analysis applies to a region in the Southeast, roughly corresponding to a large river basin. (The data presented in this example are crude and are not intended to be representative of any specific area.) The region encompasses portions of two ecoregions (2200 and 2300), several forest types and two physiographic zones. Silvicultural management takes place throughout the region although the erosion impacts differ.

In this case, a regional agency (such as a State Water Quality Division or a Regional Council of Governments) instructed the analyst to evaluate erosion-control strategies that could be applied throughout the region in a cost-effectiveness analysis framework to determine a set of programs corresponding to various levels of erosion reduction. Specifically, the objective included two steps: (1) determine cost-effective programs for effectiveness levels of 25 and 45 percent on a region-wide basis, and (2) indicate the total costs of these programs.

Step 2. Identify Alternative Strategies

Step 2A. Stratify the Region--

To identify alternative strategies, the region was stratified into areas. This was done so that each strategy would be representative of an area in terms of erosion control costs and effectiveness. Stratification was accomplished on the basis of two features: (1) physiographic characteristics and (2) forest types. With reference to local information and to Chapter 2 of this report, the system in Table 18 was developed.

TABLE 18. REGIONAL STRATIFICATION

1. Mountains
    a. Yellow Pine
    b. Virginia Pine
    c. Oak-Hickory

2. Piedmont
    a. Loblolly-Shortleaf Pine
    b. Oak-Hickory

Step 2B. Identify Strategies for Each Area--

Strategies for each area were identified with the help of foresters and hydrologists familiar with local conditions. The following procedure was used:

(1) Tables in Chapter 2 were used to determine erosion potentials associated with each forest type and for various silvicultural activities in each area.

(2) Cost-effective strategies were developed in response to these potentials. In some cases, cost-effectiveness analysis was used to identify the best combinations of controls for an area. (See Example 1 for details of these procedures.)

(3) Three estimates were made for each strategy corresponding to three levels of effectiveness. These were generally a low, medium, and high level representing approximately 20-, 40-, and 60-percent local effectiveness. (See Example 1 for details of this procedure.)

As a result of this procedure, the alternatives shown in Table 19 were identified. The table shows, for example, that for the oak-hickory type found in the mountains a cost-effective strategy with primary control emphasis on access and harvest activities can reduce erosion impact in that type by approximately 20 percent when applied at a relatively low level. By incurring higher costs, the same strategy could increase its local effectiveness to 40 percent. Thus, for each forest type in the two physiographic areas there is one erosion control strategy which can be applied at any of three levels. Each of these levels represents an alternative although a higher level for a strategy includes the lower levels.

TABLE 19. EROSION CONTROL STRATEGIES

Area	Strategy[1]	Level of Effectiveness[2]
1. Mountains		
a. Yellow Pine	Access-Cultural treatment	1. Low 2. Medium 3. High
b. Virginia Pine	Access-Cultural treatment	4. Low 5. Medium 6. High
c. Oak-Hickory	Access-Harvest	7. Low 8. Medium 9. High
2. Piedmont		
d. Loblolly-Shortleaf Pine	Cultural treatment-Harvest	10. Low 11. Medium 12. High
e. Oak-Hickory	Access-Harvest	13. Low 14. Medium 15. High

---

[1] Entries indicate the major emphasis of controls comprising the strategy.

[2] Approximate values are
Low = 20%
Medium = 40%
High = 60%

Assessment of Costs and Effectiveness:

Step 3. Estimate System Effectiveness

In order to normalize local values into measurements reflecting the system effectiveness of various strategies on a river basin scale, an estimate was required of the relative proportion that silvicultural management in each of the areas made to the total erosion impact within the basin (Table 20).

TABLE 20. SYSTEM EFFECTIVENESS OF STRATEGIES

Area	Acres[1]	Relative Share[2]	X	Alternative Strategy	= System Effectiveness
1. Mountain					
a. Yellow Pine	20,000	20%		1. 20%	4%
				2. 40	8
				3. 60	12
b. Virginia Pine	15,000	15		4. 20	3
				5. 40	6
				6. 60	9
c. Oak-Hickory	5,000	5		7. 20	1
				8. 40	2
				9. 60	3
2. Piedmont					
a. Loblolly-Shortleaf Pine	35,000	35		10. 20	7
				11. 40	14
				12. 60	21
b. Oak-Hickory	25,000	25		13. 20	5
				14. 40	10
				15. 60	15

---

[1] Average number of acres undergoing silvicultural management annually.

[2] Percentage share of total silvicultural erosion impact occurring within the total area.

Two steps were taken to accomplish this:

(A) The number of acres managed for silviculture were estimated for each area. And an estimate for each area was made for the average annual erosion per acre due to silvicultural management.

(B) The products of these two values were then translated into percentages reflecting the relative share of the river basin erosion occurring in each area.

These relative shares are shown in the column "Relative Share" in Table 20. The table shows, for example, that approximately 60 percent of the silviculture-related erosion within the basin occurs in the Piedmont Area (e.g., 25 + 35 percent), 40 percent in the Mountain Area, and 35 percent in the loblolly-shortleaf pine type.

Assessment of Costs and Effectiveness:

Step 4. Estimate Total Costs for the Region

In Table 21 three cost estimates were made for every strategy corresponding to the three levels of local effectiveness. (Please note: Only one strategy for each type is shown in Table 21.)

TABLE 21. TOTAL COSTS FOR REGION

Area	Acres*	Alternative	Unit Cost/Acre	Step 4 Total Cost (in thousands)
1. Mountain				
a. Yellow Pine	20,000	1.	$ 2.50	$ 50
		2.	15.00	300
		3.	90.00	1800
b. Virginia Pine	15,000	4.	3.00	45
		5.	10.00	150
		6.	40.00	600
c. Oak-Hickory	5,000	7.	20.00	100
		8.	40.00	150
		9.	60.00	350
2. Piedmont				
d. Loblolly-Shortleaf	35,000	10.	5.00	175
		11.	20.00	700
		12.	130.00	4550
e. Oak-Hickory		13.	3.00	75
		14.	15.00	375
		15.	35.00	875

*Average number of acres annually undergoing active silvicultural management.

Table 22 summarizes the information pertaining to the alternative strategies.

TABLE 22. SUMMARY OF ALTERNATIVE STRATEGIES

Step 2A Area	Step B An Erosion Control Strategy	Step 2B Percent Level of Effectiveness	Step 3 Percent System Effectiveness	Step 4 Total Cost For Region (In thousands)
1. Mountains				
a. Yellow Pine	Access-Cultural treatments	1. Low (20%)	4%	$ 50
		2. Medium (40%)	8	300
		3. High (60%)	12	1800
b. Virginia Pine	Access-Cultural treatments	4. Low (20%)	3	45
		5. Medium (40%)	6	150
		6. High (60%)	9	600
c. Oak-Hickory	Access-Harvest	7. Low (20%)	1	100
		8. Medium (40%)	2	150
		9. High (60%)	3	300
2. Piedmont				
d. Loblolly-Shortleaf	Cultural treatments-Harvest	10. Low (20%)	7	175
		11. Medium (40%)	14	700
		12. High (60%)	21	4550
e. Oak-Hickory	Access-Harvest	13. Low (20%)	5	75
		14. Medium (40%)	10	375
		15. High (60%)	15	875

Erosion-control cost estimates were made on an annual average per acre basis (Cost per acre x Number of acres = Total cost). That is, the estimates were intended to reflect the average annual cost per acre of applying the erosion-control strategy to silvicultural management within the area. The costs depended largely upon controls selected to comprise the strategy and their individual costs. Again, cost estimates were made by persons familiar with local conditions. In addition, reference was made to cost estimates by Federal and State agencies and private forestry companies in the region.

Because the objective of the analysis is to determine the most cost-effective programs for the region as a whole, it was required that system effectiveness (Step 3) be compared with total incremental costs (Step 4). Cost estimates are based on a unit cost (i.e., silvicultural type). Because a different number of acres are undergoing active silvicultural management in each unit in each year, to obtain a total cost for erosion control requires that the total erosion control cost for each area and silvicultural unit within it be determined. Thus, the product of the unit cost (in Table 21, for example, 2.50 per acre in the Yellow-Pine type) and the number of acres affected (20,000 acres) will yield the total cost for each area ($50,000), shown also in Table 23.

Analysis and Choice

Since the objective could not be reached with the application of a single erosion-reduction strategy in one area only, the regional program was made up of strategies that affected various areas within the region. Thus the program was composed of strategies affecting different areas, although the intensity at which they were applied could differ from area to area.

Assessment of Costs and Effectiveness:

Step 5. Determine Marginal Costs and Effectiveness for Each Level of Strategy

Marginal analysis was used to evaluate the strategies and determine how they should be combined to produce a cost-effective program. To begin, the marginal cost and marginal effectiveness values for each level of each strategy were determined (Table 23).

TABLE 23. MARGINAL ANALYSIS

Area	Step 5			Step 5		Step 6
	Alter-native	Cost		Effectiveness		Marginal* C/E Ratio
		Total Cost	Marginal Cost	System	Marginal	
		(in thousands)				
1. Mountain						
a. Yellow Pine	1.	$ 50	$ 50	4	4	12.5
	2.	300	250	8	4	62.5
	3.	1800	1500	12	4	375.0
b. Virginia Pine	4.	45	45	3	3	15.0
	5.	150	105	6	3	35.0
	6.	600	450	9	3	150.0
c. Oak-Hickory	7.	100	100	1	1	100.0
	8.	150	50	2	1	50.0
	9.	300	150	3	1	150.0
2. Piedmont						
d. Loblolly-Shortleaf Pine	10.	175	175	7	7	25.0
	11.	700	525	14	7	75.0
	12.	4550	3850	21	7	550.0
e. Oak-Hickory	13.	75	75	5	5	15.0
	14.	375	300	10	5	60.0
	15.	875	500	15	5	100.0

---

*(Marginal Cost) ÷ (Marginal Effectiveness) = Ratio

To illustrate, Alternatives 1 through 3 refer to the application of a single erosion-control strategy to the yellow pine forest type in the mountains. Alternative 1 is a low level of control, while Alternatives 2 and 3 are more intensive applications of the same strategy to obtain greater erosion control.

Marginal cost will be defined here to refer to the addition to total cost that reflects a higher level of erosion control. Thus, the marginal cost of Alternative 1 is $50,000, or the "additional" cost of obtaining 4 percent system effectiveness. For Alternative 2, the marginal cost is $250,000 ($300,000 - $50,000) and for 3 it is $1,800,000.

Marginal effectiveness is calculated in the same fashion. For the first three alternatives, the marginal effectiveness values are all a constant 4 percent.

The marginal value for each strategy must be calculated in the same manner.

Analysis and Choice:
Step 6. Determine Cost-Effectiveness Ratios

To determine the most cost-effective program based upon a desired level of erosion-control effectiveness, the alternatives should be ranked in order of increasing marginal cost-effectiveness ratios (see Table 23). The marginal cost-effectiveness ratio is the quotient of the marginal cost and marginal effectiveness values.

Analysis and Choice:
Step 7. Rank Alternatives in Order of Cost-Effectiveness Ratios

Based upon these ratios, the alternatives for this example have been ranked in increasing order and are shown in Table 24. (See also Step 5B of Example 1.)

TABLE 24. ALTERNATIVE RANKINGS

Step 7					Step 8
		Cost		EFE	Cumulative
Rank	Alternative	Marginal Cost (X1000)	Total Cost Cumulative (X1000)	Marginal Effectiveness	System Effectiveness
1.	1	50	50	4	4
2.*a.	4	45	95	3	7
b.	13	75	170	5	12
3.	10	175	345	7	19
4.	5	105	450	3	22
5.	14	300	750	5	27
6.	2	250	1000	4	31
7.	11	525	1525	7	38
8.	15	500	2025	5	43
9.	7	100	2125	1	44
10.	8	50	2175	1	45
11.*a.	6	450	2625	3	48
b.	9	50	2775	1	49
12.	3	1500	4275	4	53
13.	12	3850	8125	7	60

---

*At this rank, two alternatives have the same marginal ratio.

Analysis and Choice:

Step 8. Determine Cumulative System Effectiveness

Once alternatives have been ranked (Step 7, Table 24 above), cumulative system effectiveness must be determined. These values are obtained by adding together the marginal effectiveness values (Table 24 above) for each of the alternatives with higher ranking. For example, Alternative 5 has a cumulative system effectiveness of 22, or the sum of values of all the alternatives ranked above it (i.e., 4 + 3 + 5 + 7 + 3 = 22).

Analysis and Choice:

Step 9. Determine Program that Meets Desired Level of Effectiveness

To determine the program that will meet a desired level of effectiveness, such as the 25-percent level specified in the objective, reference is made to the Table 22. A system effectiveness of 27 percent can be obtained by utilizing the alternatives with the first five rankings. This includes Alternatives 1, 4, 13, 10, 5, and 14. The program, composed of alternatives relating to levels of intensity for strategies, is:

Alternatives	Strategy intensity	Area
1	Low	Mountains--Yellow pine
5	Medium	Mountains--Virginia Pine
10	Low	Piedmont--Loblolly-Shortleaf
14	Medium	Piedmont--Oak-Hickory

The reason Alternatives 4 and 13 do not appear in the above tabulation is that they are included in Alternatives 5 and 14 (5 refers to an alternative which is a medium level intensity application of strategy 2--simply an extension of Alternative 4, and similarly for Alternatives 13 and 14). This program would be approximately 27 percent effective for controlling erosion within the river basin at a total cost of $750,000.

Using similar logic, to obtain a 45-percent level of effectiveness, the most cost-effective program would be:

Alternative	Strategy intensity	Area
2	Medium	Mountain--Yellow pine
5	Medium	Mountain--Virginia pine
8	Medium	Mountain--Oak-Hickory
11	Medium	Piedmont--Loblolly-Shortleaf
15	High	Piedmont--Oak-Hickory

This program would be approximately 45 percent effective and cost $2,175,000 annually.

To show how responsive program costs are to increasing levels of erosion control, Figure 20 was developed from Table 24. It illustrates how the higher levels of control are increasingly more expensive. The figure also shows that by implementing all strategies at their highest level of effectiveness, a maximum of 60 percent of the expected erosion could be controlled in any year.

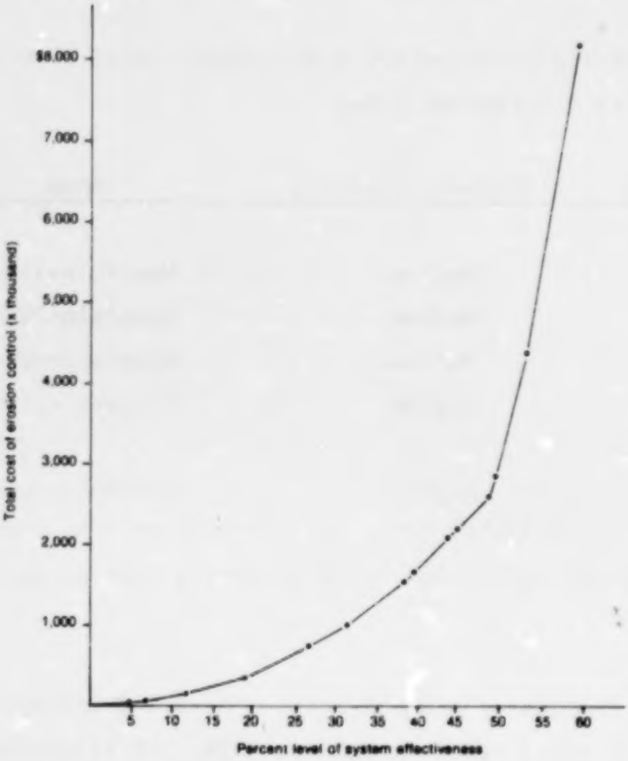


Figure 20. Program costs.

. . . .

To conclude this example, one major limitation should be noted. The total costs associated with the various levels of effectiveness embodied in the alternative programs are the costs only for controlling erosion. This analysis was conducted investigating silviculture on a regional basis--in a region where silviculture may comprise a significant segment of the economy. Evaluating only the incremental costs of erosion control does not account for economic ramifications throughout the rest of the economy--changes in the relative prices of wood products, improved efficiency in production, or employment changes, for example. These impacts can only be estimated by using a general equilibrium model. Even so, cost-effectiveness analysis provides a good evaluation of on-site costs.

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GLOSSARY

Sources for most of the terms defined in this glossary include Bannock, Baxter, and Reed's A Dictionary of Economics; Ford-Robinson's (editor) Terminology of Forest Science, Technology Practice and Products; SAF's Forestry Terminology; and Schwarz, Thor, and Elsner's Wildland Planning Glossary. A few definitions have come from the EPA report, Forest Harvest, Residue Treatment, Reforestation and Protection of Water Quality.

Aerial logging: See "Logging systems--aerial."

Balloon logging: See "Logging systems--aerial."

Benefit-cost analysis: A technique which attempts to identify and evaluate the social costs and social benefits of investment projects. The difference between benefit-cost analysis and ordinary investment appraisal methods is the stress on the social costs and benefits.

Broadcast burning: Allowing a controlled fire to burn over a designated area within well-defined boundaries, for reduction of fuel hazard, as a silvicultural treatment following harvesting or thinning, or both.

Broadcast seeding: Sowing over a wide area, especially by hand although this kind of seeding also includes airplane and helicopter seeding, and manually operated "cyclone" seeding.

Brush hook: A heavy slashing tool used in much the same way as an axe and having a wide blade, generally curved.

Burning--pile: Commonly referred to as "pile and burn." This involves piling the slash after lopping and subsequently burning the individual piles.

Burning--spot: A modified form of broadcast burning in which only the larger accumulations of slash are fired and the fire confined to these spots.

Burning--swamper: Otherwise known as progressive burning. This is a burning of the slash as it is piled.

Cable logging: See "Logging systems--cable logging."

Clearcutting: See "Silvicultural practices."

Controlled burn: (1) The planned application of fire to natural fuels, residue left on a site after a logging operation and other slash, with the intent to confine it to a predetermined area. (2) Any deliberate application of fire to an area where control is exercised in some particular respect.

Cost-effectivesness analysis: A comparison of the cost or resource inputs with the performance of program outputs as they relate to a specific goal. This analysis is used when the benefits of the program are largely unquantifiable.

Crawler tractor: See "Logging--crawler tractor."

Cross slope: Slope of the road bed.

Cut-and-fill: The process of earth moving by excavating part of an area and using the excavated material for adjacent embankments or fill areas.

Cut slope: See "Road structure terms."

Design speed: Speed determined for design and correlation of the physical features of a road that influence vehical operation. Maximum safe speed.

Discounting (present value): A method for weighting effectiveness or costs that occur in future time periods against those that occur in the immediate future. The relative importance given to future costs or effectiveness depends upon the discount rate. The discounting relationship for future costs would be:

$$C(o) = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t}$$

where

C(o) = the present value of all future costs
t = the measure of time (months, years)
n = total number of time intervals
r = the discount rate

Discounting for effectiveness can proceed in the same manner.

Drainage dip: A dip in the road surface which runs at a slight angle to the cross section of the road, thus allowing water to drain off the road surface.

Economic efficiency: Considered most simply, economic efficiency is achieved when the value of what is produced by any set of resources exceeds by as much as possible the value of the resources; or when the least valuable set of resources is utilized in producing any particular worthwhile output.

Economic suboptimization: As used in the text, it refers to the possibility for calculating a least-cost solution which, when compared with benefits, may not be truly efficient.

End hauling: Hauling of excavated material (dirt) from a "cut" area to a "fill" area.

Erosion, accelerated: Erosion much more rapid than normal erosion, natural erosion or geologic erosion, and occurring primarily as a result of the influence of the activities of man, or in some cases, of other animals or natural catastrophes that expose bare surfaces.

Even-aged management: The actions that will result in a forest, crop, or stand composed of trees having no or relatively small differences in age.

Even-aged stand: A forest stand composed of trees having no, or relatively small, differences in age. By convention the maximum difference admissible is generally 10 to 20 years, though with rotations of less than 100 years differences up to 25 percent of the rotation period may be admissible.

Fill slope: See "Road structure terms."

Ground lead: "See Logging, ground lead."

Harvesting practices: In this report, specifically in the ecoregion tables, this term is used to mean cutting systems. The systems are clearcutting, seed tree, selection, and shelterwood.

High lead: "See "Logging, high lead."

Insloped surface: See "Road structure terms."

Intermediate cultural treatments: See "Intermediate cutting."

Intermediate cutting: Any removal of trees from a regular crop or stand between the time of its formation and the harvest cutting.

Internal rate of return: That rate of interest which, when used to discount cash flows associated with an investment project, reduces its net present value to zero.

Interplanting: Setting young trees among existing forest growth, planted or natural. May include the planting of land partly occupied by brushwood or scrub.

Jammer: There are many kinds of high lead equipment--portable steel towers, mobile shovel yarders or mobile loggers which are track mounted, and the jammer--either track or wheel mounted and equipped with a steel or wood boom. These units come with either a one- or a two-drum winch. Jammer logging is limited to uphill yarding of clearcuts.

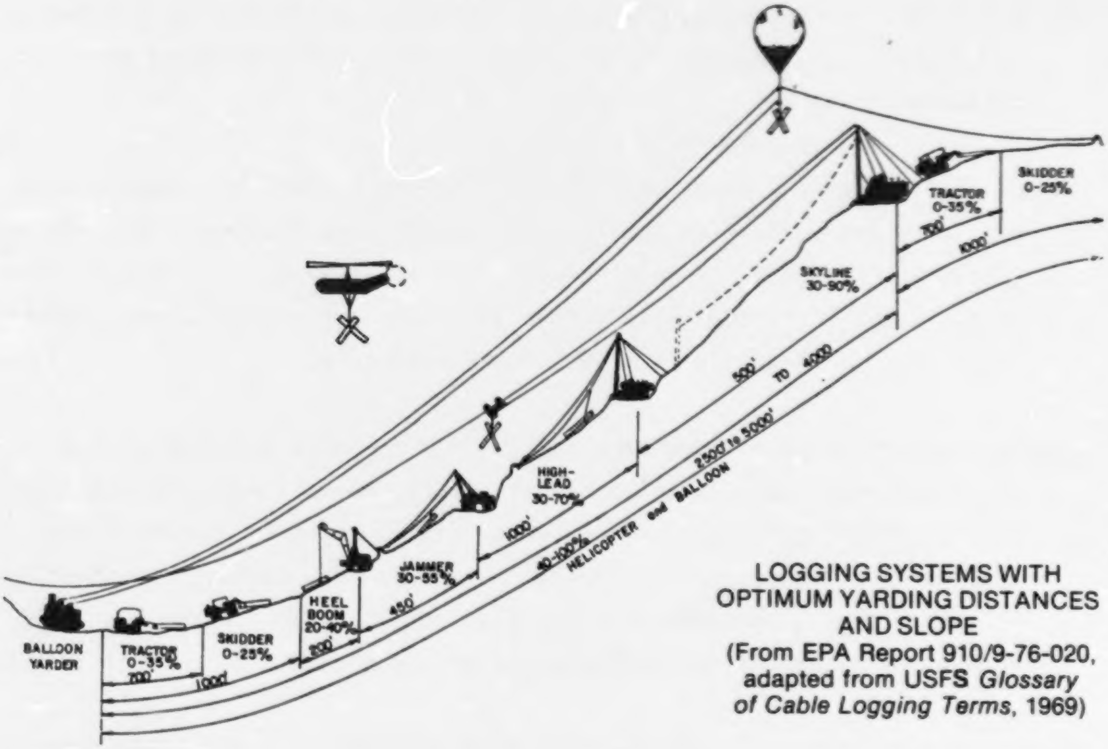
Logging--crawler tractor: Used for logging and normally equipped with a winch and wire rope. When yarding on steep, swampy, rocky or difficult terrain, the tractor can be located on stable terrain, and the winch used to skid logs a short distance to the tractor. Various attachments, primarily arches and sulkies, have been developed for tractors which reduce the degree of contact between log and ground.

Logging, ground-lead (low-lead cable logging): A method for transporting logs from the stumps to a collecting point by dragging them along the ground with a powered cable passing through a block fastened close to ground level.

Logging, high-lead: A method for transporting logs from the stumps to a collecting point by using a powered cable, passing through a block fastened high off the ground, to lift the front end of the logs clear of the ground while dragging them.

Logging--rubber-tired skidder: A tractor developed during the 1950's specifically for logging. Rubber-tired wheel skidders have the advantage of greater speed over crawler tractors, but the disadvantage of limited traction.

Logging systems:


BALLOON YARDER
TRACTOR 0-35%
700'
1000'
SKIDDER 0-25%
HEEL BOOM 20-40%
200'
JAMMER 30-55%
450'
HIGH-LEAD 30-70%
1000'
40-100% HELICOPTER and BALLOON
2500' to 5000'
500' TO 4000'
SKYLINE 30-90%
TRACTOR 0-35%
700'
1000'
SKIDDER 0-25%

LOGGING SYSTEMS WITH OPTIMUM YARDING DISTANCES AND SLOPE
(From EPA Report 910/9-76-020, adapted from USFS *Glossary of Cable Logging Terms*, 1969)

Logging systems--aerial: A system for hauling timber from the stump to a collecting point which employs aerial means of transportation--e.g., balloons or helicopters.

Logging systems--balloon: See "Logging systems--aerial."

Logging systems--cable logging: Cable systems are designed to yard logs from the felling site by a machine equipped with multiple winches commonly called a yarder. Cable logging is highly efficient for logging steep rough ground on which tractors cannot operate. Some cable systems can operate in any direction upslope, downslope, and along the contour. Cable systems could be classified as either high lead, skyline and balloon.

Logging systems--full suspension: See "Logging systems--skyline" and "Logging systems--aerial."

Logging systems--skyline: "Skyline logging" is a particular type of cable logging. A method for transporting logs from stumps to collecting points that uses a heavy cable stretched between high points (such as in tall trees braced with guy lines) to function as an overhead track for a load carrying trolley. Logs are lifted up by cables or other devices attached to the trolley and powered cables are used to move the load back and forth along the main cable.

Lop and scatter: Lopping the slash created by primary conversion and spreading it more or less evenly over the ground without burning. Primary conversion is the first stage of converting timber into any kind of product. It comprises the topping, trimming, laying off, baring, cross-cutting, and initial sawing up, hewing, or cleaving of a felled or fallen tree.

Lopping: Chopping branches, tops, and small trees after felling, into lengths such that the resultant slash will lie close to the ground.

Mass movement: Downslope, unit movement of a portion of the land's surface--i.e., a single landslide or the gradual simultaneous, downhill movement of the whole mass of loose earth material on a slope face.

Mass-wasting: A general term for any of the variety of processes by which large masses of earth material are moved downslope by gravitational forces--either slowly or quickly.

Outsloped surface: See "Road structure terms".

Partial equilibrium analysis: The analysis of the determination of equilibrium conditions for a small part of the economy.

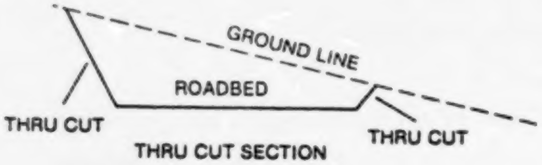
Regeneration--artificial: Artificial reproduction is obtained either by planting young trees or by applying seed, sometimes called "direct seeding."

Regeneration cutting: (1) Any removal of trees intended to assist regeneration already present or to make regeneation possible. (2) "Regeneration cutting" applies generally to the logging stands of rotation age or greater, and stands below rotation age which cannot economically be held any longer because of poor stocking, health, thrift, quality, or composition. (3) "Regeneration cutting" applies to all cutting in virgin stands and to all cutting in cutover stands where the overwood components of the stand are over rotation age.

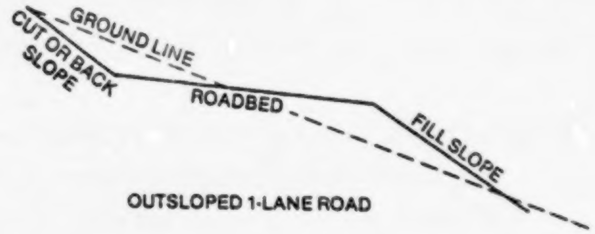
Regeneration--natural: Natural regeneration is obtained from seedlings which originate by natural seeding or from sprouts. Natural regeneration following harvesting requires a source of viable seed. Seedbed preparation for natural regeneration is often accomplished by logging and slash disposal. However, in many cases deliberately-planned additional site preparation work is also needed.

Release cutting: (1) Freeing a tree, or group of trees, from more immediate competition by cutting, or otherwise eliminating, growth that is overtopping or closely surrounding them. (2) Three principal operations come under this classification: (a) Treatments to free desired growing stock trees from over-story vegetation; principally, scrub trees, brush, and vines that inhibit their growth or desirable development. (b) Treatments to prevent development of brush and trees that threaten to overtop desired growing stock trees. (c) Removal of grass, weeds, or brush from around individual seedlings or small trees to release them from competition for soil moisture, shade, or smothering as under matted grass or weeds. (3) Cutting an immature stand to free the crop trees from excessive competition by removing the excess of an undesired age class (such as a young age class which because of excessive numbers is competing severely with an older but desired regulated age class).

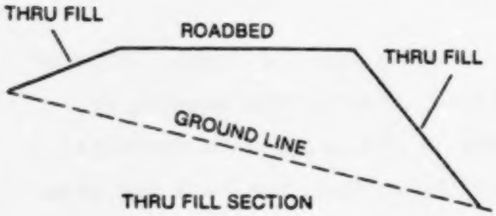
Road structure terms:


GROUND LINE
ROADBED
THRU CUT
THRU CUT

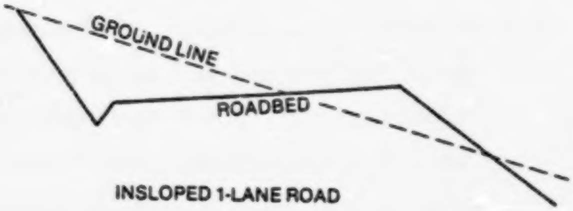
THRU CUT SECTION


GROUND LINE
CUT OR BACK SLOPE
ROADBED
FILL SLOPE

OUTSLOPED 1-LANE ROAD


THRU FILL
ROADBED
THRU FILL
GROUND LINE

THRU FILL SECTION


GROUND LINE
ROADBED

INSLOPED 1-LANE ROAD

Rubber-tired skidder: See "Logging--rubber-tired skidder."

Scalping: Paring off low and surface vegetation, together with most of its roots, to expose a weed-free soil surface, generally preparatory to sowing or planting thereon. Done in spots only.

Scarification: To break up the surface of the topsoil in order to expose mineral soil.

Sediment: Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

Seed tree: See "Silvicultural practices--seed tree."

Selection: See "Silvicultural practices--selection."

Shelterwood: See "Silvicultural practices--shelterwood."

Silviculture: Generally, the science and art of cultivating (i.e., growing and tending) and managing forest crops for profit based on a knowledge of silvics. More particularly, the theory and practice of controlling the establishment, composition, constitution, and growth of forests.

Silviculture--clearcutting: (1) Removal of virtually all the trees, large or small, in a stand in one cutting operation. This is the meaning of "clearcutting" in its narrowest sense and in its usage as a technical term of silviculture. The true clearcutting method lays bare the area treated and leads to the establishment of an even-aged stand. (2) The term "clearcutting" is also loosely applied to any type of cutting in which all the merchantable timber is cut and all trees that cannot be utilized profitably are left. This broader usage of the term is technically incorrect but is so common that it is sometimes prudent to speak of clearcutting in the silvicultural method sense as "complete clearcutting."

Silviculture--clearcutting system: A silvicultural system in which all the trees are cleared over a considerable area at one time. Regeneration is generally artificial, but natural regeneration is sometimes possible by seeding from the air, from adjacent stands, or from seed and/or the ground.

Silviculture--seed tree: (1) A tree purposely left standing at the time of cutting in a forest, for the purpose of producing seed for regeneration of trees in the cut-over area. (2) A tree selected, and often reserved, to be a source of seed for collection.

Silviculture--seed tree system: (1) Removal in one cut of the mature timber from an area, save for a small number of seed bearers left singly or in small groups. (2) A regeneration cutting where the planned source of the new stand is from seed existing on, or to be produced by, trees standing on the cut-over area. The cutting removes all the mature timber except for the number of seed trees which are needed to provide seed for reproducing the stand.

A cutting which leaves the number of seed trees needed to provide the optimum amount of seed required to restock, but not overstock, the area.

Silviculture--selection cutting: Removal of mature timber, usually the oldest or largest trees, either as single scattered trees or small groups at relatively short intervals, commonly 5 to 20 years, repeated indefinitely, by means of which the continuous establishment of natural reproduction is encouraged and an uneven-aged stand is maintained.

Silviculture--selection system: An uneven-aged silvicultural system in which trees are removed individually, here and there, from a large area each year. Regeneration is mainly natural and the timber crop ideally all different ages.

Silviculture--shelterwood cutting: Cutting which leaves enough trees to provide about half shade or more on the ground. In some places, more trees than are needed to provide shade for reproduction must be left in order to prevent windthrow.

Silviculture--shelterwood system: Even-aged silvicultural systems in which (in order to provide a source of seed and/or protection for regeneration) the old crop is removed in two or more successive "shelterwood cuttings," the first of which is ordinarily the seed tree cutting and the last is the final cutting, any intervening cuttings being termed removal cuttings.

Skidding: A loose term for hauling loads by sliding, not on wheels. A timber may slide more or less wholly along the ground (ground skidding); or with its forward end supported (high-load skidding); or even wholly off the ground--sliding along a cable--during its main transit (aerial skidding).

Skyline logging: See "Logging systems--skyline."

Slash: The residue left on the ground after timber cutting and/or accumulating there as a result of storm, fire or other damage. It includes unutilized logs, uprooted stumps, broken or uprooted stems, branches, twigs, leaves, bark, and chips.

Species--associate: Otherwise known as accessory species. A species of less value than the principal species but sometimes useful in assisting the development of the latter and liable to influence in some degree the method of treatment. Both accessory and secondary species are collectively termed associated species.

Species--principal: The species to which the silviculture of a mixed forest is primarily directed, either for its (or their) economic or protective value. Please note, a species intrinsically of higher economic value than another may be less economically important because of its lower frequency of occurrence and therefore, not the principal species.

Species--secondary: A species of inferior quality and/or size, and of relatively little or no silvicultural value, associated with the principal species.

Tree injection: A deliberate introduction, by pressure or simple absorption, of a chemical--generally a water-soluble salt in solution--into the sapstream of a living tree. Purposes include, to kill the tree or to prevent or control disease or infestation.

Thinning: Cuttings which are made in immature stands to stimulate growth of the remaining trees in order to increase the total wood yield.

Thinning--commercial: Commercial thinning is practiced on older stands for which the thinned trees have marketable value as pulpwood, poles, sawlogs, etc. The objective of commercial thinning is to provide more desirable tree spacing and to concentrate growth on the remaining trees as a means of increasing total yield of wood. It nearly always improves the general quality of the stand. The age at which stands are thinned is determined both by tree growth rate and market demand for specific types of wood products. In contrast to precommercial thinning, commercial thinning requires entry into stands with logging equipment for removal of felled trees.

Thinning--precommercial: The basic objective of precommercial thinning is to increase merchantable yield by concentrating productivity of the site into few stems per acre. Such thinning is also valuable for control of mortality due to insects and disease. Precommercial thinning is accomplished either with chemicals or by mechanical methods primarily powersaws.

Thru cut: See "Road structure terms."

Thru fill: See "Road structure terms."

Turnout: Double lane section along a single lane road which allows passage of two vehicals traveling in opposite directions.

Understory: The trees and other woody species growing under a more or less continuous cover of branches and foliage formed collectively by the upper portions of adjacent trees and other woody growth.

Uneven-age management: The course of actions involved in maintaining a forest or stand, composed of intermingling trees that differ markedly in age.

Uneven-aged stand: A forest stand composed of intermingling trees that differ markedly in age. By convention, a minimum range of 10 to 20 years in generally accepted, though with rotations of less than 100 years, 25 percent of the rotation period may be the minimum.

Water bar: A ridge made across a hill road to divert water to one side.

Yarder: A machine equipped with multiple winches used in the cable logging system.

Yarding: The operation of hauling timber from the stump to a collecting point.

YUM yarding (yarding unmerchantable material): A practice of yarding the larger size classes of residues from recently logged units. Unmerchantable material is yarded during or following log removal and piled at the landing. In some instances, especially designed cable logging systems are used to yard residues.